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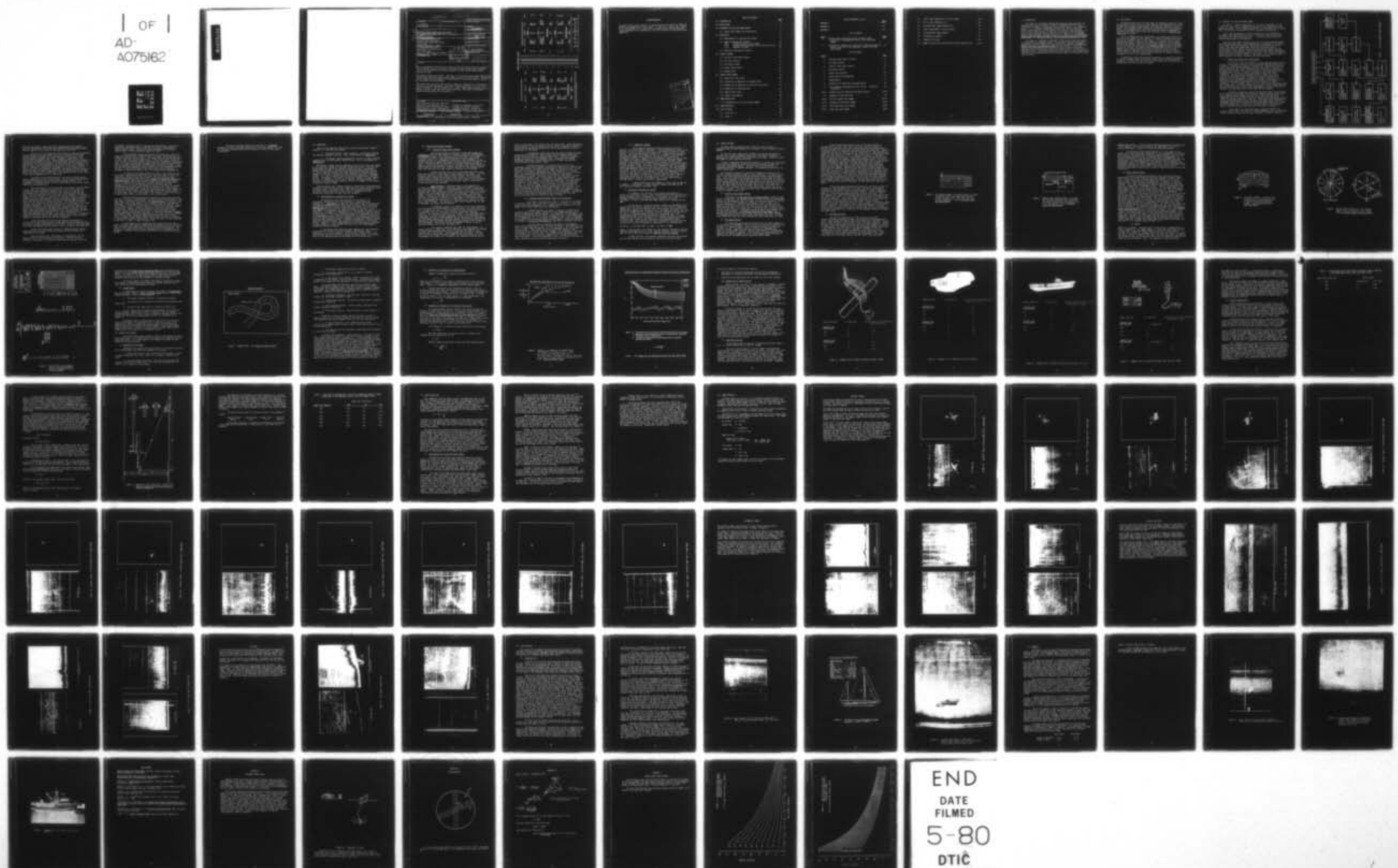

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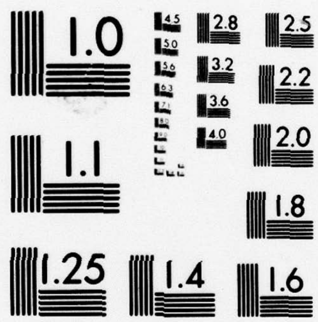


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16. Abstract

This is a manual of instruction for using the side scan sonar system in searching for underwater objects, to be used in conjunction with standard search manuals, such as the National Search and Rescue Manual (CG 308) and the manufacturers' instruction book.

The general approach is twofold. The first is to present logical search methods for conducting a broad area search using a sensor such as a side scan sonar. The second is to present objective methods of interpreting side scan sonar images of objects on the seafloor by the operator.

Side scan sonar records of four specific targets are presented in an interpretive portfolio to enable assessment of the sonar system's capability and to train unskilled operators. The four targets are: a small single engine aircraft, an automobile, a 40-ft. steel boat and a Coast Guard buoy. Two cases of opportunity involving sunken vessels are presented.

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side scan sonar, EG&G side scan sonar, sonar image interpretation, search patterns, search effectiveness, contact identification, contact investigation, interpretive portfolio, underwater search

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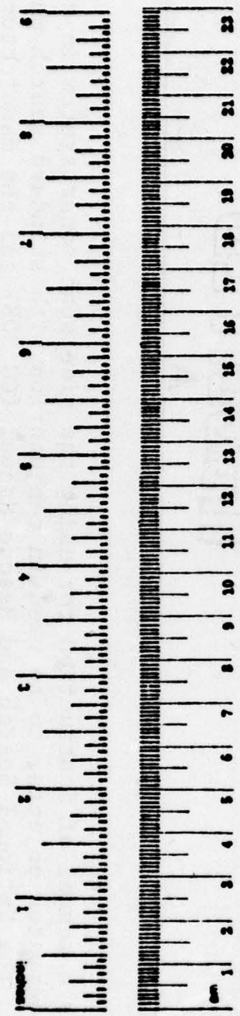
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

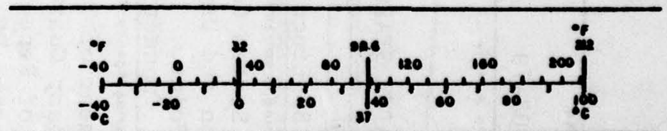
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## 1.0 INTRODUCTION

This report is intended to provide the relatively unskilled side scan sonar operator who has a general scientific background with sufficient information to conduct an effective side-scan sonar search for an underwater object. It is intended to supplement existing publications concerning standard search practice and the operation of side scan sonar equipment. A full listing of publications of interest is contained in the bibliography, however, the three major publications used are: Chapter 8 of the National Search and Rescue Manual (CG 308), Manual for the Operations Analysis of Deep Ocean Search, and Instruction Manual, Side Scan Sonar System Mark 1B (EG&G).

This report is intended to supplement CG 308 and the Instruction Manual in the practice of underwater search. For advanced information regarding computation of search probabilities and other search methods, the Manual for Operations Analysis of Deep Ocean Search may be consulted. Insofar as possible the same nomenclature and notation used in these publications is employed herein to provide consistency and standardization in the practice of underwater search. The general approach of this report is toward Coast Guard applications to underwater search for stationary objects on the seafloor using side scan sonar.

## 2.0 APPLICATION

The general need within the Coast Guard for underwater search for sunken objects has historically been for those whose physical characteristics, such as composition, dimensions and general conditions were known prior to the search. This a priori target information is combined with other information gained from the search plan such as environment and position parameters to determine the effectiveness of the side scan sonar system in detecting and identifying the target.

To aid in determining this effectiveness, an interpretive portfolio of side scan sonar images of known targets, in a known environment with a known position is included as part of this report. If a certain level of sonar system effectiveness is desired, the interpretive portfolio can be used to determine the optimal values of the operational parameters of the equipment such as range setting, track spacing, transducer depth and mode to be used in the search. Usually, the highest level of system effectiveness is desired, however, certain other factors may take priority over level of system effectiveness; for example a low resolution sweep may be used for a quick initial search of the area when the possibility exists of persons remaining entrapped in the hull of a sunken vessel.

In addition to using the interpretive portfolio as a method to establish the relation between sonar system search effectiveness and the operational parameters, it may be used as a training aid to enable unskilled operators to recognize certain cues to identify targets.

## 3.0 PLANNING THE SIDE SCAN SONAR SEARCH

The search is normally administered by the Search Coordinator on site. CG 308 lists four items of information that are of vital importance to the search coordinator: (1) An adequate description of the target, (2) the search area, (3) the best search pattern, and (4) the proper track spacing.

These items are reached by a logical sequence by use of information available at the beginning of a search and by further investigation of the incident by the Search Coordinator, and are events that occur during the Search Planning phase of the operation.

Side Scan Sonar Search Planning involves an interaction between several activities and events that is best demonstrated by a diagram, as in Figure 1. This diagram shows the methodology involved for establishing the initial search. Once the search begins new intelligence is gained such as: environmental factors, bottom configuration and possible targets that may require further investigation. These considerations may require modification of the search area or establishment of a new area. This further refinement of the search plan is presently outside of the scope of this discussion, and is better treated in the basic references previously mentioned.

### 3.1 Target Intelligence and Investigation

This activity forms the foundation of knowledge upon which the whole structure of the search planning is built, therefore thorough research and diligence in investigating apparently unrelated and insignificant leads may reveal information that may ultimately simplify the search or localize the position of the target. Marine incidents such as sinkings and mysterious disappearances of vessels are usually attended by much speculation and false information and it takes a skilled investigator to glean the useful information. Persons closely connected with the incident are usually reluctant to come forward with information that may be of great value, especially when the government is conducting a formal investigation. Fortunately, the Coast Guard's reputation as a humanitarian organization in the eyes of many persons connected with the sea often elicits their cooperation. Local fishermen, highly skilled in positioning themselves within the fishing areas, can usually pinpoint the position of any incident they have seen with great accuracy, and are very knowledgeable concerning locations of "hangups" or places where their fishing gear may have snagged.

The position references used by the observers should be scrutinized with respect to gyro compass error, magnetic compass deviation, LORAN system hop or skywaves or any inherent sensor errors. Positions obtained by independent navigation systems are often inconsistent with each other, e.g., a visual fix does not agree with a radar fix. These conflicting positions must be assigned weighting factors and included in the search area. Often the fathometer reading does not agree with the charted depth offshore or in areas where the bottom survey is inaccurate, therefore depth is not a reliable primary reference and should be used only as confirming information.

If the vessel is a historical wreck, extensive research into journals, ship's logs, naval board of inquiry proceedings, bills of lading and private letters of the period may reveal important information, keeping in

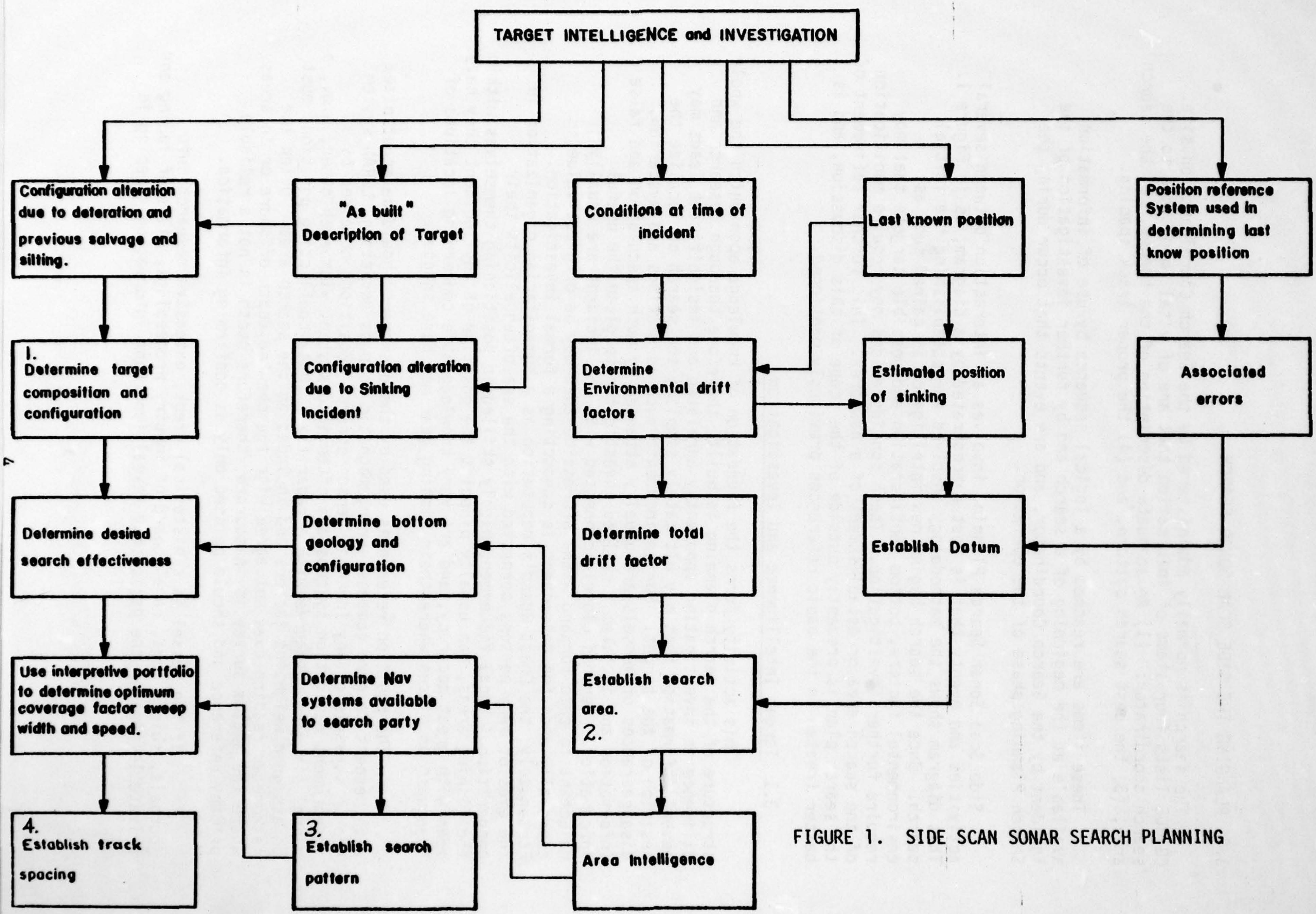



FIGURE 1. SIDE SCAN SONAR SEARCH PLANNING

mind that the names of places and coastal geography may have changed. Physical deterioration of the wreck over time and previous salvage attempts may have significantly altered the configuration of the vessel.

The "as built" configuration of the vessel can usually be determined from photographs or builders plans which may be obtained from the owner, builder, insurance company, marine certification societies such as the American Bureau of Shipping and Lloyds, fisherman's cooperatives, pilot associations and seaman's unions. These photographs and plans are valuable in classifying and identifying possible side scan sonar contacts gained during the search by using the techniques to be explained later in this report. The material used in the construction of the vessel, such as wood, fiberglass or metal is important in determining the composition of the target and the quality of signal to be expected. Generally, the acoustic signal from wood is weaker than that from metal, producing a less distinct mark on the recorder. Special techniques, such as "profiling", to be described later in this report can be used to compensate for this deficiency.

Alterations to the configuration of the vessel or object may be caused by the nature of the sinking incident, such as collision or explosion, and by deterioration due to age and previous salvage attempts. This information is combined with the "as built" description to provide the target composition and configuration.

The investigation into the conditions at the time of sinking should include time of last sighting, projected track of the vessel, cause of sinking, estimated time vessel remained afloat since last sighting, and environmental drift factors such as wind, sea, surface current and tide state. The last known position of the vessel may be reported by a witness, another vessel or aircraft, a radar net, or the vessel itself. It may also be computed as a dead reckoning position from a previously reported position. For our purposes we shall define sinking as the time the vessel or object leaves the sea surface and reaches the bottom. The estimated position of sinking is not necessarily the last known position if the vessel is not under continuous observance. The sinking may occur at a time later than the causative incident, and the vessel may drift, therefore environmental drift factors must be considered in estimating the position of sinking. The SAR Manual treats the subject of environmental drift and establishing the search area quite completely and therefore it will not be discussed here. A simplifying assumption may be made in most cases at this point: the object or vessel will not drift once it has reached the sea bottom. Thus continuous updates of the datum area due to drift are unnecessary.

Error associated with the position reference system used in determining the last known position are combined with the estimated position of sinking to produce a datum point, line or area. The drift error and search craft error are combined with the datum in order to establish the search area.

Search area intelligence consists of information concerning the search area and its relation to the environment and surroundings, and is independent of the target.

Once the search area is determined, an investigation into the physical nature of the area should be conducted. Tides and currents, bathymetry, the nature of the bottom and any bordering land mass should be

considered. The bottom surficial geology and configuration is important in determining the effectiveness of the side scan sonar in detecting and identifying the target. A bottom with rock outcroppings will produce a greater number of false targets and hamper the search.

The navigational systems available to the search party limit the search area and the type of search pattern to be used. Search patterns are treated in section 4 of this report. The system should be the best available in order to minimize search vessel error. If the search area is within 20 miles of land, a precision location system such as a transponder system may be used. This type of system must be setup by the search party, thus sufficient time and resources must be made available before the search can begin. Care must be taken that geographical points selected for the transponder locations are within line-of-sight range of the search area to ensure effective coverage, or valuable time may be lost in re-orienting the transponder net.

The search effectiveness probability (SEP) is the probability that the target is detected and identified, given that the target is within the search area, during that particular search. This definition has some simplifying assumptions from that given in <u>Manual for Operations Analysis of Deep Ocean Search</u>, namely that the target location is evenly distributed within the search area and that there is 100% coverage of the area with no overlap. By use of the interpretive portfolio technique described subsequently in this report and knowing the nature of the target and bottom, the search effectiveness probability may be determined for a given search vessel speed and sweep width. Generally, the search effectiveness probability is higher for slower speeds and narrower sweep widths which take a longer period of time. Thus, if a time factor is not involved, a high desired level of search effectiveness can be achieved on the initial search.

The search effectiveness may be improved by covering the area more than once. This may be accomplished by running a second search pattern in the same area or increasing the coverage. The <u>coverage factor</u> is the ratio of the sweep width to the track spacing. The coverage is this ratio expressed as a percentage. The coverage should never be less than 100%, or gaps will occur in the search. Thus, if the track spacing is 100 yards and the sweep width is 200 yards the coverage is 200%, and each point within the search area is covered twice. The use of a high coverage is often more effective than running a second search because the target is viewed from the opposite <u>aspect</u> on the second pass; a possible target thus has two "looks" within a relatively short period of time, allowing a comparison and possible identification. There is a speed for the towfish that minimizes distortion that is discussed in the section on contact investigation. During the search a faster speed may be desirable in order to reduce the search time.

If the target is still undetected after completion of the search pattern and more intelligence has been gained concerning the target and search area, a second search pattern may be run over an improved search area. Thus basically, the search plan returns to the beginning of the diagram and the procedure is repeated, omitting those steps where no new information has been gained.

**The search planning procedure set forth here is a <u>suggested</u> procedure as to how to go about planning for a side scan search. It is not all-inclusive and modifications may be necessary in order to meet special circumstances.**

## 4.0 NAVIGATION

There are two important reasons why an accurate navigational system is necessary in a side scan sonar search:

1. The search pattern is more systematic, allowing more thorough and complete coverage of the area. This is the property of completeness.

2. The target's absolute geographical position is known, enabling repeated passes for more complete identification. This is the property of repeatability.

Navigational systems describe geographical points within the area covered by the system by a geometric coordinate system consisting of lines that are prescribed by the type of navigational system being used. Navigational systems that are used in side scan sonar search are systems that prescribe: (1) line of constant distance from a known geographical reference station, examples of this type of system are radar ranges and electronic transponder systems. (2) lines of constant bearing from a known geographical reference station. An example of this type of navigational system is a visual compass bearing. (3) hyberbolic lines; lines of constant difference between the distances to two geographical reference stations. An example of this type of navigational system is LORAN.

Once the search area is generally known, a navigational system should be selected to cover the area with the highest degree of accuracy possible within the capabilities of the search party. When the navigational system is selected a search pattern may be set up that is compatible with the navigational system and will cover the area completely.

### 4.1 Requirements of a Navigational System

As discussed in the first paragraph of this section, the navigational system should have the properties of completeness and repeatability. Completeness in space and time requires that the system cover the complete geographical search area during the entire time of the search. Repeatability requires that the system enable an observer to return to the same geographical position with a specified degree of accuracy. If the requirements of completeness and repeatibility are not met, the search will be ineffective. An example of incompleteness of a navigational system is when a reference point is lost due to excessive distance or interference such as fog or electromagnetic noise. Spatial incompleteness will produce "holidays" or areas that have unwittingly not been covered, or areas that cannot be covered using the same reference stations. Incomplete coverage would require using an additional reference station, thus producing a discontinuity in the search pattern. Temporal, or time incompleteness will cause the search to be broken off and resumed at a later time when the fog lifts or the electromagnetic propagation conditions improve.

If the navigational system has good repeatability, some compromise may be made with regard to spatial or temporal completeness. Good repeatability will allow a smoother transition over a discontinuity in the search pattern caused by shifting to another reference station, or resuming a search at the same point where it was broken off at an earlier time.

## 4.2 Types of Navigational Systems

### 4.2.1 Constant Distance (Arc) Systems

Distance measurement navigational systems employ radar and transponders which are both electronic in nature, using very high frequency electromagnetic waves. This causes two basic limitations in the system: (1) a distance limitation in that the observer must be within sight of the reference station, (2) a propagation limitation in that atmospheric or sea interference such as weather may produce a severe reduction in strength of the signal. Strong wind and sea conditions will produce interference such as radar sea return and excessive rolling of the search vessel which reduces the effectiveness of the directional antennas required for such systems, however under such conditions the sonar system will probably not be deployed.

Constant distance lines from a fixed object describe circles about that object of a radius equal to the distance to the object. For short distances (less than 5 miles) these constant distance lines have a high curvature which produces two problems: high curvature in the coordinate system produces a distortion in the resulting sonar traces, (2) a high degree of skill on the part of the helmsman of the search vessel is required to follow tracks with high curvature.

Radar ranging is a technique known to most operators of military and commercial vessels, and radar systems are commonly installed in most potential search vessels. A known geographical point is selected that provides a good radar target over the entire area to be searched. In order to reduce errors, the target should be small and unambiguous. Smallness of the target in relation to the beam width (resolution) ensures that the radar operator is observing the same point on the target and unambiguity ensures that the radar operator is observing the same target. This target may consist of a fixed geographical point such as a lighthouse, small island, or a buoy with a radar reflector. The accuracy of radar ranging depends upon the type of equipment, the target, and the operator.

A transponder system is not commonly used for ship navigation and consequently must be provided by the search party. The system consists of an interrogator unit that is installed aboard the search vessel, and at least 2 transponders that are installed at selected navigational reference stations. The principle of operation is as follows: the interrogator emits a signal that is received by each transponder, after a fixed time delay the transponders each emit a coded response that is received by the interrogator. The interrogator measures the time delay between the out-going signal and the reception of each transponder response, which corresponds to the distance to each transponder. The distance to each transponder in meters is usually displayed automatically by the interrogator unit.

This system is preferred over radar for three reasons: (1) target selection is simplified, (2) the need for a radar operator to interpret the radar image and measure the range is eliminated, (3) there is less inherent error in the system. The transponders may be placed at locations which provide an optimal coordinate system for the search area, i.e., the transponders are located so as to produce large intersecting angles and are

within line-of-sight to all points within the search area. Large intersecting angles between the constant distance lines for each transponder increase the accuracy of the system; and being within line-of-sight ensures the spatial completeness of the system.

A transponder system eliminates the target strength and image interpretation problems of a radar system, allowing automatic operation, greater reliability and less inherent system error. Precision navigation systems are usually of the transponder type. The Motorola Miniranger transponder system has an advertised accuracy of 3 meters and the Cubic Western Autotape system that of 1 meter.

In actual practice it is often difficult to set up a transponder system with an optimal configuration, especially in coastal areas due to the nature of the coastline with respect to the search area. If the coastline is straight or convex (such as capes and points), it is often difficult to set up two transponders whose lines intersect at a satisfactory angle. An intersecting angle of $30^{\circ}$ is a minimum for satisfactory performance of a system. Locations inshore that are high enough to ensure line-of-sight operation such as radio towers and light houses may be considered as possible sites. In selecting a transponder site, the location and elevation of the site are the primary considerations. Also important, although to a lesser degree, is the availability of electrical power and security. If electrical power is not available fresh batteries must be provided each day, thus making periodic maintenance visits necessary. Also since the equipment is expensive and subject to theft and vandalism, the security of the location must be considered. These two problems are usually solved by assigning a man to set up and service the transponder. Lighthouses and coastal radio masts are operated by the Coast Guard and have good security, and most have A.C. electrical power available.

4.2.2 <u>Constant Bearing Systems Visual Line-of-Position</u>

The visual line-of-position (LOP) is traditionally the method of position finding used in coastwise navigation or piloting. A visual LOP may be obtained by two methods: (1) a compass bearing (azimuth) to a fixed object, (2) a visual range using two fixed objects.

A compass bearing to an object is obtained by measuring the horizontal angle to the object from North, or the compass heading to the object as measured by a marine compass. This method has the advantage in that the LOP can be plotted directly onto a navigational chart. The disadvantages of this method are: (1) it is subject to compass errors, and (2) it becomes less accurate with increasing distance from the object. A good text decribing this method is <u>Piloting and Dead Reckoning</u>, published by the Naval Institute.

A visual range is produced by bringing two fixed objects, usually some distance apart, into line with one another. Two objects are said to be "in range" when the observer is on the extension of the line connecting the two objects. These objects may be any convenient features of the coastline such as an unusual building, flagpole, rock formation, or tree that are located so as to form a range. This method has the advantages that it is very accurate and is not subject to compass error, and does not require special equipment. The main disadvantage is that it is difficult to plot on a chart since the features used may not be marked on the chart.

### 4.2.3 Hyperbolic Systems

The navigation systems previously discussed require the observer to be within sight of the coast. It may be necessary to search in an area that is too far offshore to be able to use constant distance or visual systems. One of the most accurate systems that is continuously available in the outer continental shelf waters of the U.S. is LORAN-C. Other offshore navigational systems such as celestial and satellite systems are not continuously available. LORAN is called a hyperbolic system because the LOP's are formed by a constant difference in distance to two stations. LORAN produces a coordinate system of hyperbolas of constant time difference, as measured in microseconds. The area of coverage typically extends for hundreds of miles offshore. Within the Loran-C entire groundwave area, the distance between the measured position and the actual position is less than 500 meters with a 95% confidence interval using a standard deviation of .1 microsecond (CG-222-4). Closer to shore the accuracy is better and depending upon the location of the receiver in the area the accuracy may be 100 meters. An accuracy of 100 meters is marginal for use with side scan sonar, however it can be used successfully if the object of the search is large (as an ocean-going ship) allowing a wide sweep width. A large track overlap or coverage factor is used to ensure spatial completeness.

A good reference for using LORAN-C is "How to Get the Most Out of LORAN-C", by CDR Robert F. DUGAN and Daniel PANSHIN, published by the Marine Advisory Program of Sea Grant, 1978.

### 4.3 Selecting a Navigational System

As a general rule, accuracy is the primary consideration in selecting a navigational system. Other considerations are the availability of special equipment and skilled operators. If the search is of high priority, equipment and operators are generally made available to the search coordinator. If this is not the case, some trade-offs for accuracy must be made.

The accuracy of a navigation system in general is determined by (1) resolution of the system in measuring the LOP, (2) the angle of intersection between LOP's, and (3) the inherent error of the system. The resolution of a system usually depends upon the sensitivity of the measuring device, e.g., the ability of a LORAN receiver to measure to within 10 meters or the ability of the optics of a bearing compass to measure to the nearest $0.1^{\circ}$. The accuracy determined by the intersecting angle between two LOP's is roughly proportional to the sine of the angle, i.e., a position determined by LOP's crossing at $30^{\circ}$ is about half as accurate as that determined by LOP's crossing at $90^{\circ}$. More accurately for those interested in the exact solution for the error along an LOP caused by a bearing error in a crossing LOP:

$$\text{LOP error} = L \sin\phi \left[\tan(90^{\circ} - \phi + \theta/2) - \tan(90^{\circ} - \phi - \theta/2)\right]$$

where L is the distance to the object, $\phi$ is the angle of intersection and $\theta$ is the total cross bearing error. A more complete treatment is given in section 1007 of the 1977 edition of Bowditch's American Practical Navigator.

In many locations a navigational system may yield only one accurate LOP, and this LOP must be crossed with an LOP from a different system.

## 5.0 SEARCH PATTERNS

The three types of search patterns used with side scan sonar, in decreasing order of effectiveness, are (1) parallel line, (2) sector, and (3) random.

In side scan sonar imaging the transducer tow-fish must be towed in a straight line in order to prevent distortion of the image. Therefore in constructing a search pattern the tracks must be straight, or nearly so, and the number of turns should be minimized.

In order to guarantee the necessary coverage of a search area, the search tracks must be followed as closely as possible to prevent any gaps from occurring in the search pattern. Two errors must be minimized for a reasonable guarantee of complete coverage: (1) navigation system error; (2) vessel control error.

The navigation system error should be minimized by the choice of as accurate a system as possible under the given conditions. The vessel control error is that resulting from the vessel deviating from the required search track. This error should be minimized by controlling the vessel as close as possible with reference to the navigational system. The ability of vessels to follow a prescribed track varies with the type of vessel and the skill of the crew. The search pattern should be constructed so as to allow the vessel to follow the prescribed track as efficiently and with as little effort as possible. This is done by setting up the search tracks along a LOP of the navigational system. This allows the search vessel operator to use the LOP as he would a compass course track.

### 5.1 Parallel Track Search Pattern

According to the National Search and Rescue Manual a parallel track pattern is used when: (1) the search area is large, (2) only the approximate location of the underwater object is known, (3) a uniform coverage is desired, and (4) the LOPs of the navigational system are nearly straight. The principal advantage in a parallel track pattern is that it minimizes the number of turns required to cover the area, especially when the track lines are oriented parallel to the major axis of the search area. A parallel track pattern is best suited to a rectangular or square search area, however this is not absolutely necessary. The National Search and Rescue Manual gives a complete run-down on the different types of parallel track search patterns. For underwater search with side scan sonar two patterns are used: Parallel Track Single-Unit Loran Line (PSL) and Parallel Track Single-Unit Arc. (PSA).

### 5.2 PSL Search Pattern

For deep-ocean search more than 20 miles off the coast, LORAN-C or its equivalent such as OMEGA is the only accurate navigational system that can be used in a large-area search. Other accurate navigational systems are available for use in the deep ocean such as acoustic transponders and satellite systems, however they are spatially and temporally discontinuous, requiring a navigational computer. The PSL pattern is used principally with hyperbolic navigation systems and has two modes depending upon the level of sophistication of the LORAN receiver aboard the search vessel.

In the simplest mode the major axis of the search pattern is oriented parallel to the loran lines. The loran lines are selected at intervals corresponding to the track spacing desired and the search vessel follows the loran line tracks back and forth across the search area. Figure 2 illustrates the basic principle of the PSL search pattern. Most mariners are unfamiliar with the skill required to keep a vessel on a close-tolerance track under open ocean conditions. Skill in steering the vessel is required in order to follow the loran track line accurately, requiring use of the loran receiver readout and the compass. Deep-ocean underwater search with loran is usually employed with a large ocean-going search vessel such as a Coast Guard cutter of the WMEC or WHEC type. On these vessels the loran receiver is located in the chart room which is physically removed from the steering station on the bridge and requires close coordination between the watch officer and the helmsman. Experience has shown that it usually takes the better part of a four hour watch to master the technique of following a loran line track accurately on a large vessel. Fortunately in the deep ocean the loran lines are nearly straight and may be approximated by a constant course through the search area. This course can initially be determined from the chart but must be corrected for any set and drift that the vessel encounters as it proceeds through the search area. Since set due to wind and seas is almost always present in the open ocean a learning process must occur on the part of the watch officers as to how much to "crab" the vessel along the track.

In the more sophisticated mode of operation, the loran receiver is connected to a mini-computer that will convert from loran coordinates to latitude and longitude and store a track consisting of several "waypoints". Waypoints are positions of course and speed change in a vessel's projected track, or in our case the beginning and end of search track legs. The mini-computer will read-out the distance and bearing to the next waypoint and the "cross track error", i.e., the distance that the vessel is off the track between two waypoints. Using this system, a pure parallel track pattern can be followed in which the major axis of the pattern can be oriented irrespective of the direction of the loran lines. Figure 3 illustrates a pure parallel single-unit track pattern (PS) in which the major axis of the pattern can be oriented for any purpose such as to enable the pattern to conform better to the search area, to allow the search vessel to ride a sea better or to increase the probability of detection of the underwater object by changing the aspect angle.

### 5.3 PSA Search Pattern

The Parallel Single-Unit Arc (PSA) pattern is used with constant-distance navigational systems, such as electronic transponder and radar. These systems are used in areas within 20 miles of the coast. An arc track is more difficult to follow than a loran line track, however, in inshore searches smaller search vessels are used which are usually easier to control. In these vessels the readout device for the navigational system can be placed in the wheelhouse (not too close to the magnetic compass) so that the helmsman, who is usually skipper or operator of the vessel can view it simultaneously with the compass and steer the vessel accordingly. These individuals are usually more experienced than the helmsmen in the routine watch sections of the larger vessels, and the initial learning process

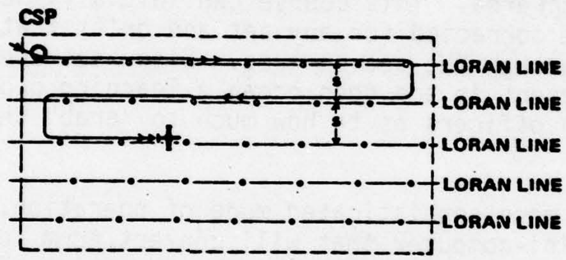



FIGURE 2. PSL SEARCH PATTERN. The search vessel (or plane) follows the Loran line tracks back and forth across the search area. The Loran lines are actually hyperbolic. From the National Search and Rescue Manual.

1. Parallel Track Single-Unit (PS).

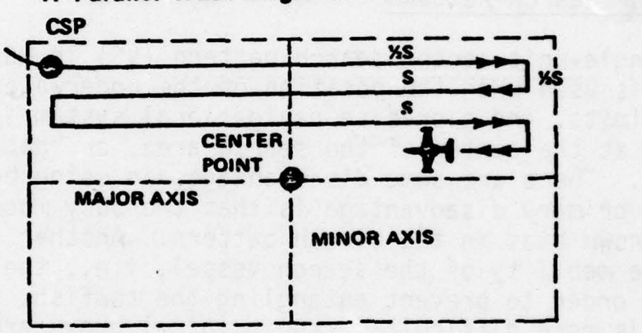



FIGURE 3. PARALLEL TRACK SEARCH PATTERN. The search unit follows tracks back and forth across the search area parallel to the major axis. S is track spacing. From the National Search and Rescue Manual.

proceeds more rapidly. In this situation the vessel operator can usually see visual landmarks, such as the position of the transponder, which aids in steering the vessel. Figure 4 illustrates the PSA search pattern.

In the parallel track search patterns it is very useful to have another LOP of the navigational system that is nearly perpendicular to the one being used for the search track in order to measure progress along the track and to determine the position of any contacts that are encountered. In offshore situations, a loran net usually has mutually perpendicular LOPs that may be used. In inshore applications more than one type of navigational system may be used. For example with a PSA search, a visual bearing to the transponder location will give a perpendicular LOP. With a transponder system which has an accuracy of 3 yards there is not too much difficulty in maintaining the search vessel within 10 yards of the desired search track (see section 6.1).

### 5.4 Sector Search Pattern

A single-unit sector search pattern (VS) in National Search and Rescue Manual is used when the position of the underwater target is known within close limits, and a precise navigational system is not available. A buoy is placed at the center of the search area, or "datum", for use as a reference mark. There are some disadvantages in using buoys in underwater searches. The primary disadvantage is that the buoy mooring may drag, thus causing an unknown bias in the search pattern. Another disadvantage is that they reduce the mobility of the search vessel, i.e., the vessel must steer around them in order to prevent entangling the towfish. Also any subsequent search effort is more difficult if the original buoys are removed or displaced. A permanent buoy should be used of a type that is visible over the entire search area. The Coast Guard has some expertise in setting buoys of this nature, however, a dan buoy consisting of a flag mounted on a long pole moored with a heavy sinker will suffice. The buoy is placed at the center of the search area such that it can be used as a navigational aid on each leg. With this method a single buoy is deployed within the search area, thus allowing greater mobility of the search vessel. The radius of the search area may be a maximum of five miles about the datum buoy, but a more practical limit is two miles. The pattern is described very completely in the National Search and Rescue Manual and is illustrated in Figure 5. This type of pattern is more effective near the center since multiple passes occur there. This pattern is also more effective in current than other search patterns using buoys since a navigational "reset" or correction occurs on each leg as the datum buoy is passed. Since the sweep width for side scan sonar is small as compared to visual methods, the central angle $\theta$ may have to be reduced. A central angle ($\theta$) is chosen using sweep width (W) and search area radius (R), such that it is an integral divisor of $360^\circ$, i.e.,

$$\theta = 360^\circ/N$$

where N is an integer. The logic used in relating $\theta$ to a coverage factor is shown in Appendix B. For 100% coverage, $\theta = \arcsin W/R$, thus $\theta$ must be small in some cases if complete (100%) coverage of the entire search area is desired. For example, for a sweep width of 400 yards and a radius of 2 miles, the central angle is 6 degrees, thus requiring thirty track legs. A trade-off can be made by reducing the coverage factor (and the subsequent probability of detection) and the number of legs. The nomograph in Figure 6 has been

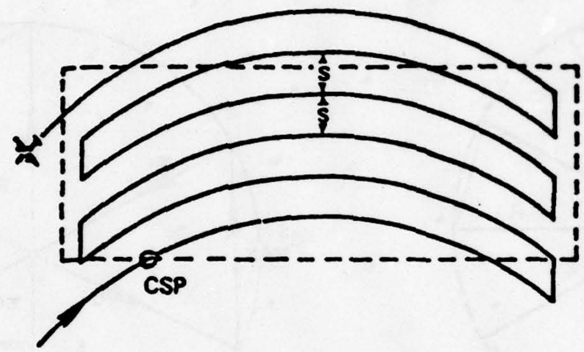



FIGURE 4. PSA SEARCH PATTERN. The search unit follows the arc lines-of-position of a constant distance navigational system. From the National Search and Rescue Manual.

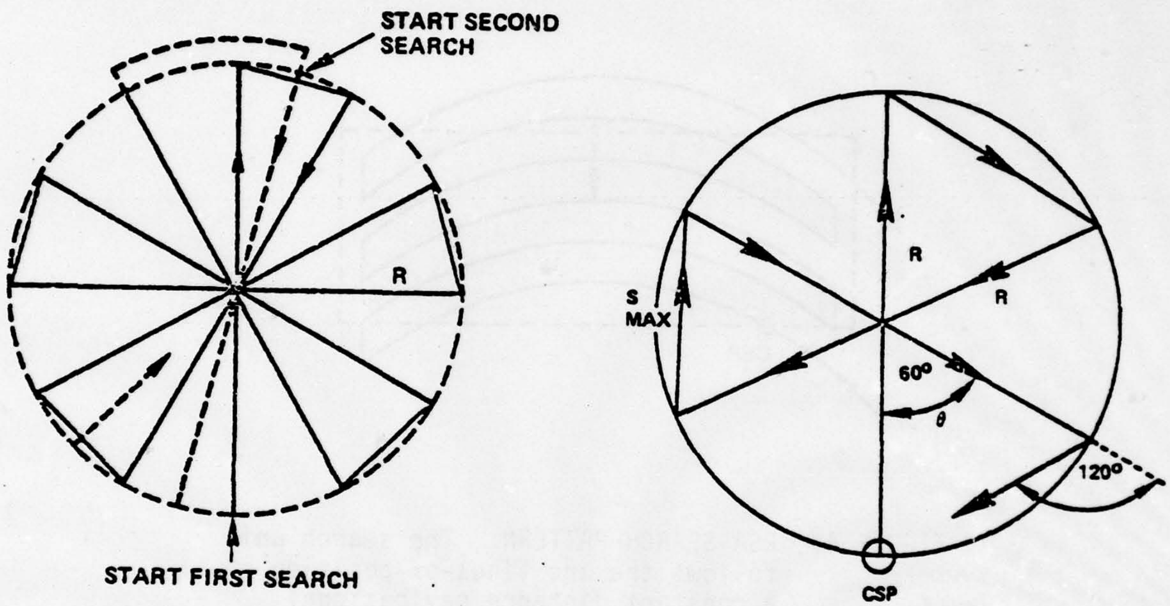



FIGURE 5. SECTOR SEARCH PATTERN (VS). The central angle (Θ) is an integral divisor of 360°. From the National Search and Rescue Manual.

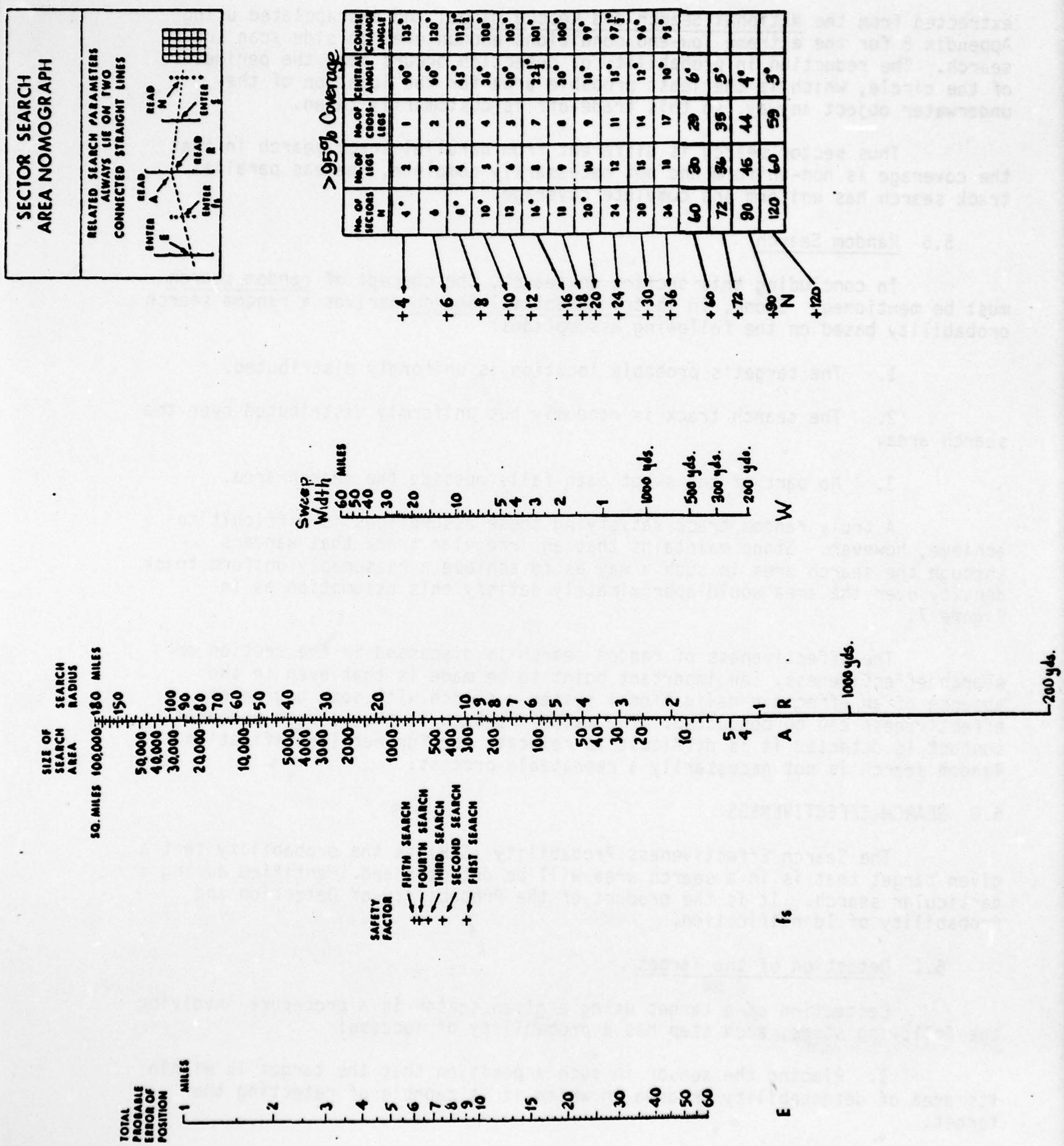



FIGURE 6. SECTOR SEARCH AREA NOMOGRAPH. Adapted from National Search and Rescue Manual.

extracted from the National Search and Rescue Manual and extrapolated using Appendix B for the extreme low-end conditions encountered in side scan sonar search. The reduction in probability of detection occurs near the perimeter of the circle, which is the least probable area for the location of the underwater object anyway, so this trade-off is customarily taken.

Thus sector search is different from parallel track search in that the coverage is non-uniform and not necessarily complete, whereas parallel track search has uniform and complete coverage.

### 5.5 Random Search

In concluding this section on search, the concept of random search must be mentioned. Stone, in Theory of Optimal Search derives a random search probability based on the following assumptions:

1. The target's probable location is uniformly distributed.

2. The search track is randomly but uniformly distributed over the search area.

3. No part of the swept path falls outside the search area.

A truly random track satisfying these assumptions is difficult to achieve, however. Stone maintains that an irregular track that wanders through the search area in such a way as to achieve a reasonably uniform track density over the area would approximately satisfy this assumption as in Figure 7.

The effectiveness of random search is discussed in the section on search effectiveness. An important point to be made is that even in the absence of an effective navigational system a search with some degree of effectiveness can be conducted. The major drawback is that once a probable contact is detected it is difficult to relocate for further identification. Random search is not necessarily a repeatable process.

## 6.0 SEARCH EFFECTIVENESS

The Search Effectiveness Probability (SEP) is the probability that a given target that is in a search area will be detected and identified during a particular search. It is the product of the Probability of Detection and Probability of Identification.

### 6.1 Detection of the Target

Dectection of a target using a given sensor is a procedure involving the following steps, each step has a probability of success:

1. Placing the sensor in such a position that the target is within its area of detectability or area in which it is capable of detecting the target.

2. The sensor marks the target, in this case the side scan sonar produces a mark on the recorder paper. This mark may be produced by the actual or true target, or a false target.

RANDOM SEARCH

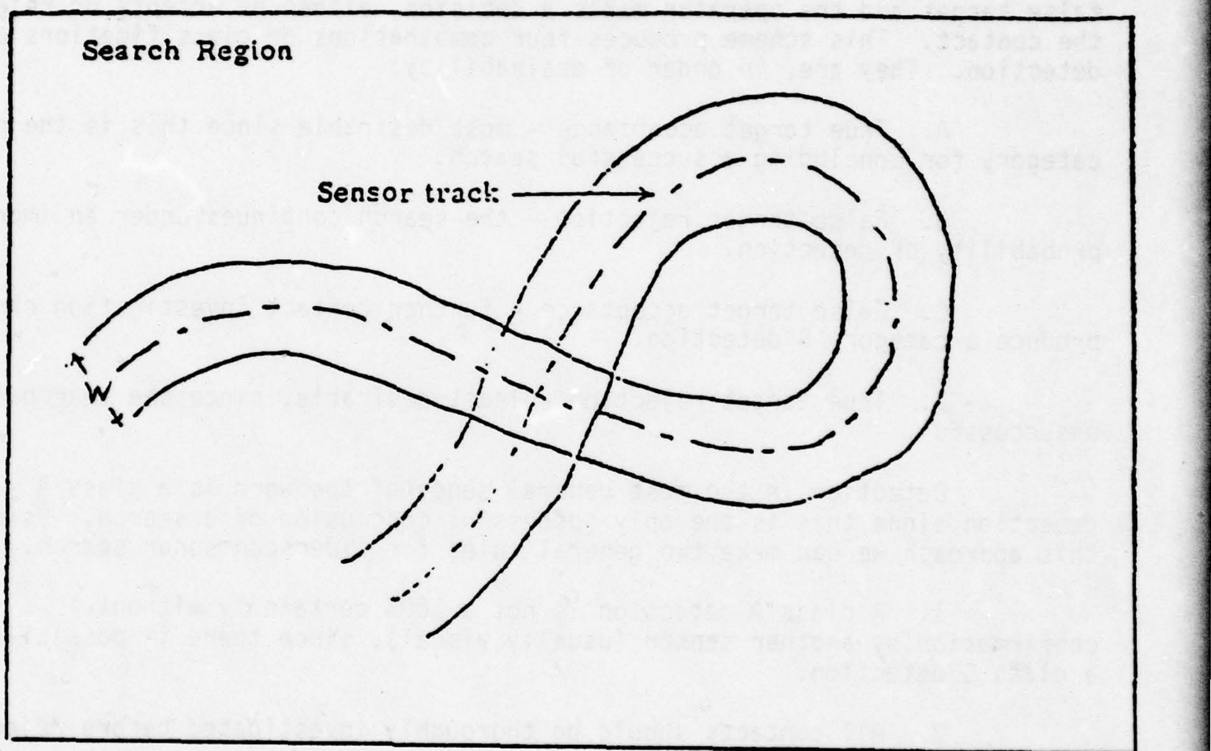



FIGURE 7. RANDOM SEARCH. From Theory of Optimal Search.

3. The operator recognizes the mark as a contact.

4. The operator decides that it is a contact of interest (acceptance) or not (rejection).

5. If the contact is of interest, further investigatin will occur to determine if the contact is actually the target. This may be by repeated passes on the contact with the same sensor or investigation by another sensor.

In this procedure two variables, each with two probable states occur: the recorder produces a mark, this may be either the true target or a false target and the operator makes a decision, either he accepts or rejects the contact. This scheme produces four combinations or classifications of detection. They are, in order of desirability:

A. True target acceptance - most desirable since this is the only category for concluding a successful search.

B. False target rejection - the search continues under an improved probability of detection.

C. False target acceptance - further contact investigation can produce a category B detection.

D. True target rejection - least desirable, since the search is unsuccessful.

Detection in the most general sense of the word is a class A detection since this is the only successful conclusion of a search. Using this approach we can make two general rules for side scan sonar search.

1. A class A detection is not a 100% certainity without confirmation by another sensor (usually visual), since there is possibility of a class C detection.

2. All contacts should be thoroughly investigated before rejection to avoid classification D.

A simplifying assumption to target detection is the definite range law. A sensor obeying the definite range law will detect a target if the target comes within the range of detectability. If we assume that the side scan sonar obeys the definite range law, the probability of detection becomes a function of the search parameters such as sweep width, coverage and navigational error. Navigational error consists of the inherent error in the navigational system being used and the error caused by the search vessel in following the search track. The navigation system error ($\sigma_N$) can be determined from the operating manual for the particular system being used or a standard text, such as Bowditch's American Practical Navigator. The search vessel error depends upon the attentiveness of the vessel operator, the nature of the current in the search area, and the ability of the vessel to respond. This error is best estimated by the operator himself, and may range from $\pm$ 10 meters for small craft to $\pm$ 100 meters for vessels operating in the ocean.

### 6.2 Probability of Detection for Random Search

Koopman's random search formula as derived by Stone is:

$$P_D = 1 - e^{-Z\frac{W}{A}}$$

where $P_D$ is the probability the target is dectected after traveling over a track length Z. A is the area of the search rectangle, and W is the sweep width. Figure 8 is a graphical representation of this search formula.

A useful application of the random search formula is that it provides a solution for worst case situation for the parallel track pattern, or any systematic search pattern. A parallel track with perfect coverage with no overlap is represented in Figure 8 by the line marked "$Z \frac{W}{A}$". If a poor navigation system is used, the search pattern is a good approximation of a random search, and the $P_D$ is represented by the line marked

"$1 - e^{-Z\frac{W}{A}}$"

### 6.3 Probability of Detection for Parallel Track Search

In a search operation using a parallel track search pattern the presence of navigational error results in unintended overlap and gaps in area coverage and thus a reduced probability of detection. Figure 9 is a graph taken from Manual for the Operations Analysis of Deep Ocean Search that shows the $P_D$ as a function of the navigational error $\sigma_N$. It reaches a limiting value which is the same as that given by the formula for random search. Using this graph the overlap may be determined from the desired probability of detection and navigational error. Keep in mind that for the limiting values a 15 percent increase in $P_D$ will require twice as much effort.

The coverage (C) is related to percent overlap ($\delta$) by the formula:

$$C = \delta/100 + 1$$

The track spacing (S) in a parallel search is related to the coverage factor and sweep width (W) by:

$$S = W/C$$

Combining these two equations, we have the Track Spacing Formula:

$$S = \frac{W}{\frac{\delta}{100} + 1}$$

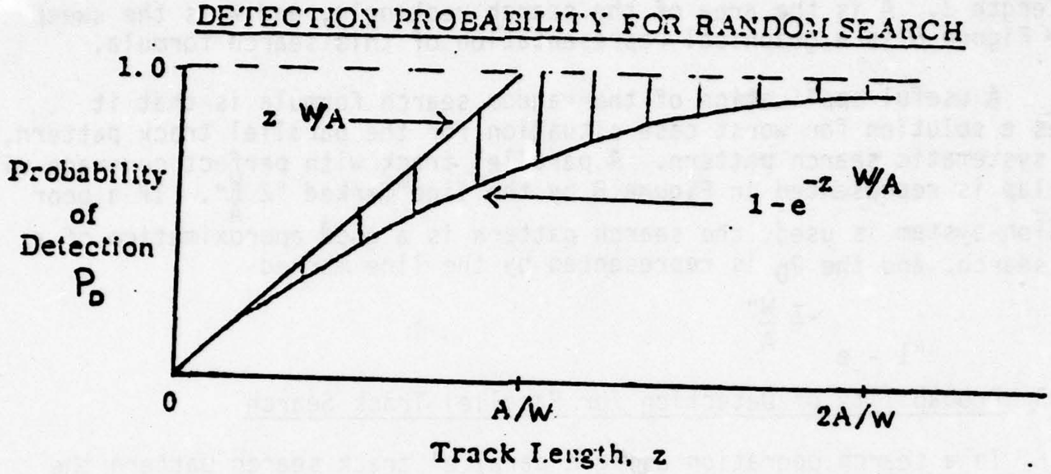
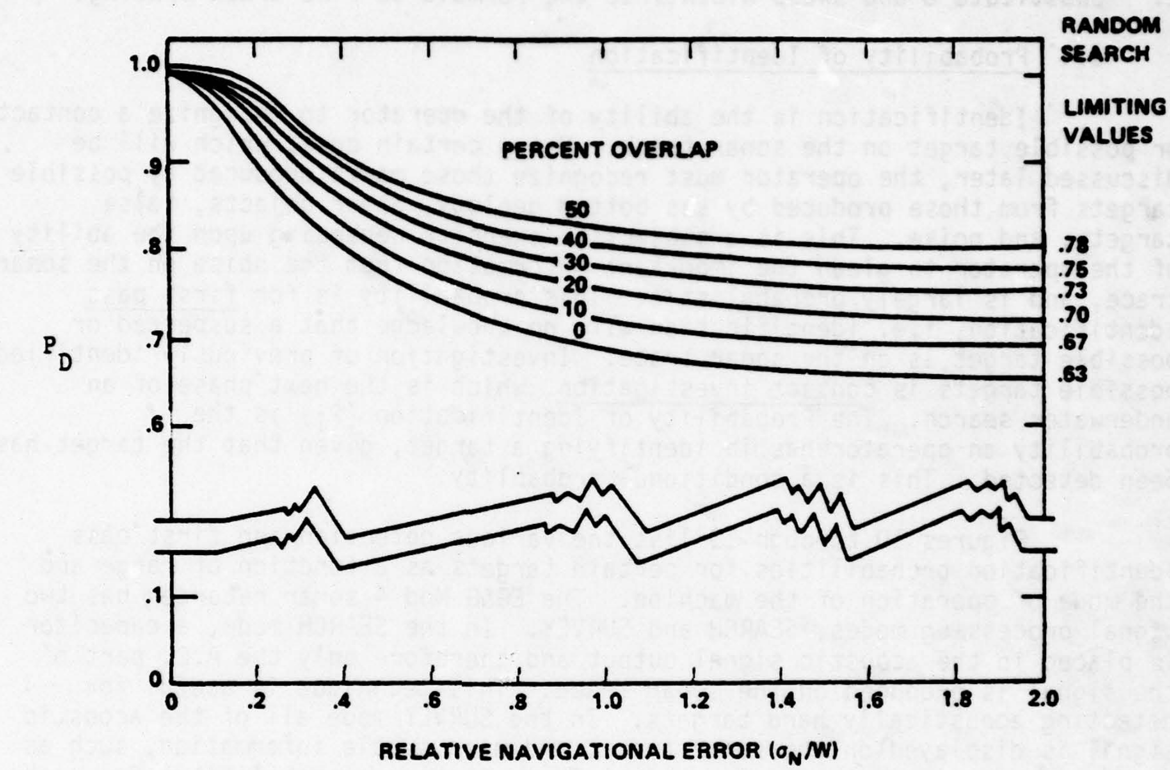



FIGURE 8. Probability of Detection For Random Search
The Probability of Detection ($P_D$) is shown as a function of the Track Length (Z).
The Track Length is expressed in terms of the value of the ratio of search area (A) and sweep width (W).
From: Theory of Optimal Search.

## THE INFLUENCE OF NAVIGATIONAL ERROR ON SEARCH DETECTION PROBABILITY




NOTES:

(1) RECTANGULAR AREA IS COVERED BY SEARCH SYSTEM USING PARALLEL SWEEPS.

(2) SWEEP WIDTH AND STANDARD DEVIATION OF THE NAVIGATIONAL ERROR ARE DENOTED BY W AND $\sigma_N$, RESPECTIVELY.

(3) IF S DENOTES THE DISTANCE BETWEEN SEARCH TRACKS, THE PERCENT OVERLAP $\delta$ IS GIVEN BY

$$\delta = 100\left(\frac{W-S}{S}\right)$$

FIGURE 9. FROM MANUAL FOR THE OPERATIONS ANALYSIS OF DEEP OCEAN SEARCH.

To use this formula to find the track spacing:

1. Use Figure 9 to determine the percent overlap ( $\delta$ ) by appropriate combination of relative navigational error and detection probability.

2. Substitute $\delta$ and sweep width into the formula to find track spacing.

### 6.4 Probability of Identification

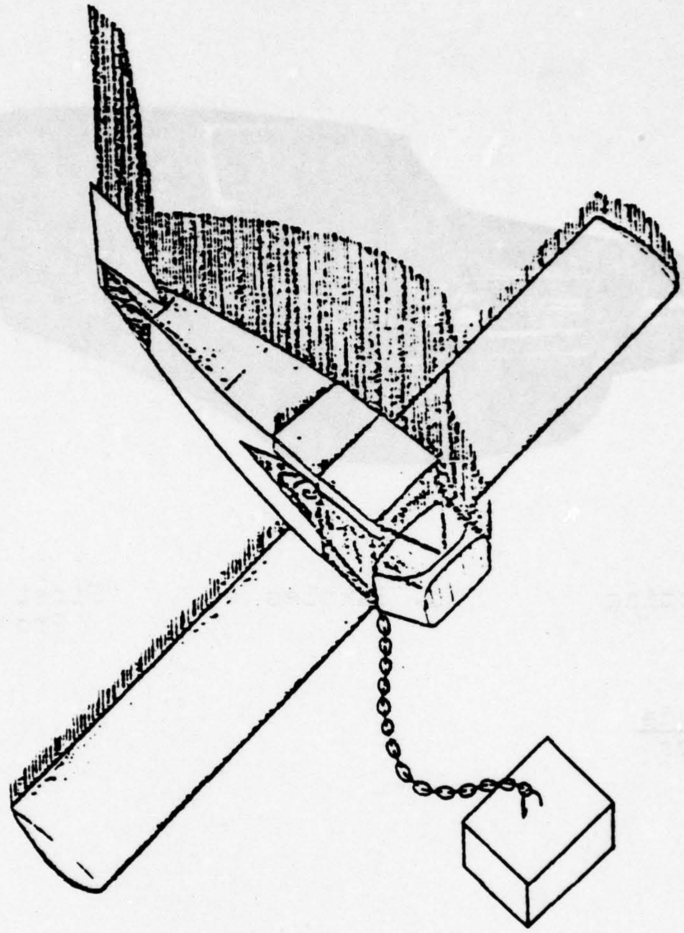
Identification is the ability of the operator to recognize a contact or possible target on the sonar track. Using certain cues, which will be discussed later, the operator must recognize those marks produced by possible targets from those produced by sea bottom geology, other objects, false targets, and noise. This is a subjective exercise depending upon the ability of the operator to glean the important information from the noise on the sonar trace, and is largely probabalistic. This probability is for first pass identification, i.e. identification with no knowledge that a suspected or possible target is on the sonar trace. Investigation of previously identified possible targets is contact investigation, which is the next phase of an underwater search. The Probability of Identification ($P_I$) is the probability an operator has in identifying a target, given that the target has been detected. This is a conditional probablity.

Figures 10 through 13 list the various detection and first pass identification probabilities for certain targets as a function of range and the mode of operation of the machine. The EG&G Mod 4 sonar recorder has two signal processing modes, SEARCH and SURVEY. In the SEARCH mode, a capacitor is placed in the acoustic signal output and therefore only the A.C. part of the signal is produced on the sonar trace. This technique is useful for detecting acoustically hard targets. In the SURVEY mode all of the acoustic signal is displayed on the sonar trace, and more subtle information, such as shadow, is available to the operator. The detection probabilitites for each target regularly increase with decreasing range, as is to be expected. The probability of identification is not so well behaved. These figures were generated by operators who had previous knowledge of the expected configuration of the sonar trace and where it was located using techniques discussed in the following section. The irregular behavior of the identification probabilities may be partially due to the small sample size in some cases, but is considered to be principally caused by the subjective nature of the identification process.

### 6.5 Identification Cues

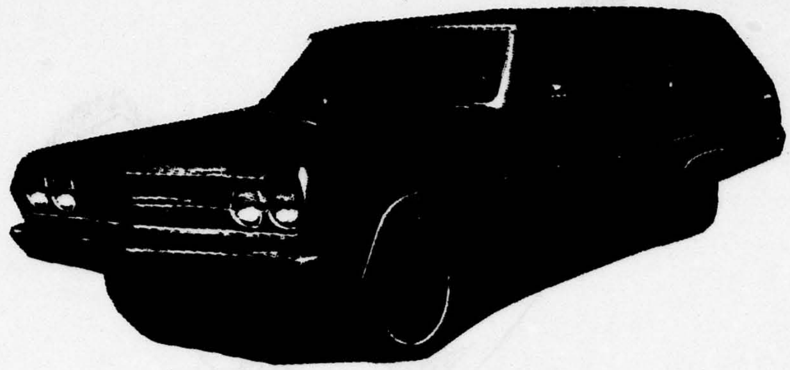
The two major types of cues used in identifying possible targets are: (1) linear features and (2) acoustic shadows.

The use of linear features in a sonar image is based upon the principle that "straight lines do not exist in nature." Straight lines in an image caused by a man-made or "cultural" object are usually sharp and well defined. Lines may be produced by the edge of an image or within the image itself by protrusions such as masts, or within the acoustic shadow. In the interpretive portfolio, the linear features present in several images are apparent. The towfish must be towed at a speed that will produce an image with the same proportions in the horizontal plane as the object. Suggested



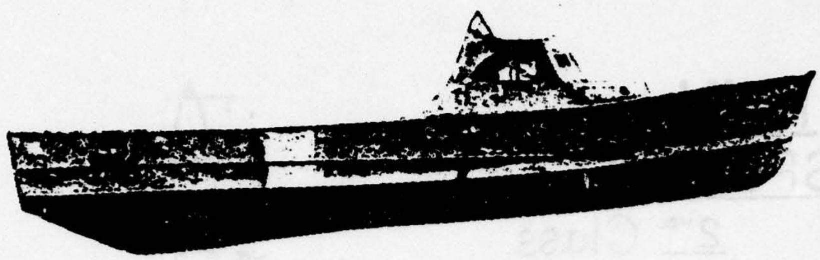
| Range Setting | No. samples | "First Pass" Identification Probability ($P_I$) |
|---|---|---|
| <u>SURVEY Mode</u> | | |
| 200 meters | 5 | .[illegible]5 |
| 125 | 10 | .75 |
| 50 | 10 | .9 |
| <u>SEARCH Mode</u> | | |
| 200 meters | 7 | .55 |
| 125 | 5 | .8 |
| 50 | 7 | .93 |

FIGURE 10. PROBABILITIES OF IDENTIFICATION FOR AIRCRAFT TARGET.



| Range Setting | No. Samples | "First Pass" Identification Probability ($P_I$) |
|---|---|---|
| SURVEY Mode | | |
| 200 meters | 4 | .67 |
| 125 | 7 | .3 |
| 100 | 3 | .5 |
| 50 | 9 | .9 |
| SEARCH Mode | | |
| 200 meters | 6 | .25 |
| 125 | 7 | .3 |
| 100 | 2 | .25 |
| 50 | 14 | .36 |

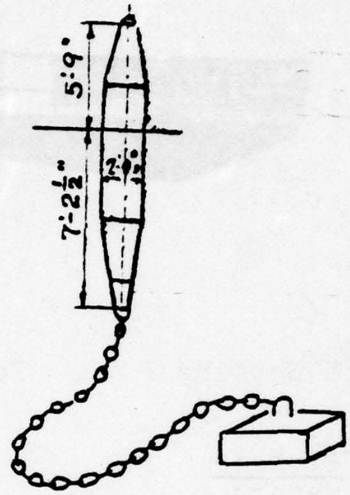
FIGURE 11. PROBABILITIES OF IDENTIFICATION FOR AUTOMOBILE.



| Range Setting | No. Samples | "First Pass" Identification Probability ($P_I$) |
|---|---|---|
| <u>SURVEY Mode</u> | | |
| 200 meters | 6 | .[illegible] |
| 100 | 6 | .7 |
| 50 | 10 | .8 |
| <u>SEARCH Mode</u> | | |
| 200 meters | 7 | .15 |
| 100 | 6 | .4 |
| 50 | 6 | 1.0 |

FIGURE 12. PROBABILITIES OF IDENTIFICATION FOR COAST GUARD 40-ft UTB.

## NUN
## SPECIAL
2ND Class




| | |
|---|---|
| BODY | 995# |
| CHAIN- | -1" 435# |
| | |
| TOTAL | 1430# |

| Range Setting | No. Samples | "First Pass" Identification Probability ($P_I$) |
|---|---|---|
| **SURVEY Mode** | | |
| 200 meters | no detection | |
| 125 | 8 | .4 |
| 100 | 7 | .6 |
| 50 | 12 | .9 |
| **SEARCH Mode** | | |
| 125 meters | no detection | |
| 100 | 4 | .5 |
| 50 | 3 | 1.0 |

FIGURE 13. PROBABILITIES OF IDENTIFICATION FOR "2NS" BUOY AND SINKER.

tow speeds are listed in Table 1. If the search vessel is travelling too slow, the time scale will be expanded causing the sonar to make multiple "looks" at the same point on any object which may be encountered. This effect will produce straight lines on the image in the vertical or time direction and is highly undesirable.

The acoustic shadow is analogous to a shadow produced by a light source in that it is an area of no reflection behind an object that protrudes up from the sea bottom. Since there is no acoustic reflection from this area, the usual bottom reflection does not occur and the shadow area prints "white", i.e, the paper is not marked in that area. The acoustic shadow can be a valuable cue in identifying objects that may protrude above the sea bottom and display a profile such as sunken vessels. Shadows produced by masts of sunken vessels that are sitting upright on the bottom show up especially well. With the EG&G system, the SURVEY mode should be used for all targets that are expected to display a profile.

### 6.6 Contact Investigation

After a contact has been identified as a possible target, more information must be obtained in order to refine the target classification. The usual process is to obtain more images by repeated passes on the target. If sufficient overlap in the search pattern is used, an image may appear at the same location on the next track (or have appeared on the last one) and the images may be compared. Using a large overlap to ensure repetitive images has the advantage that the contact will be viewed from the opposite aspect on subsequent tracks, which may show additional features in the image.

Multiple passes on the contact require a repeatable navigation system as discussed in Section 4. Another alternative is the use a temporary buoy, such as the Flip Buoy discussed in Appendix A. A buoy of this type should be kept at hand during the search and thrown over the side (being careful not the hit the towfish) when a possible target is encountered.

In refining the target classification, an attempt should be made to reduce the distortion of the image due to ship's speed. This distortion is briefly discussed in the EG&G Manual. The EG&G Recorder Mod 4 is designed such that the optimum speed is dependent only on the paper feed. This relation is shown in Table 1. The optimum speed is independent of the range setting, so range setting can be changed at will without affecting the image distortion. The 150 lines/inch paper feed density is most commonly used.

More information concerning the contact under investigation can be gathered by a technique called "profiling". In this technique, the towfish is towed at closer range and at a deeper depth than is used for search and at the optimum speed the deeper depth is used to gain the maximum benefit from the side-scan capabilities of the system by looking at the profile of the target. After several passes, on different course headings the general orientation of the target will become apparent, e.g. if the target is a sunken vessel, the heading of its major axis. Profiles of the beam and bow/stern aspect should be attempted. This will produce exaggerated shadows which may be used in image interpretation.

TABLE 1. OPTIMUM TOWFISH SPEED OVER GROUND TO MINIMIZE IMAGE DISTORTION IN THE EG&G MARK 1B MOD 4 SIDE SCAN SONAR SYSTEM

| Paper Feed (lines/inch) | Towfish Speed | |
|---|---|---|
| 200 | .75 meters/sec | 1.47 knots |
| 150 | 1.0 | 1.96 |
| 100 | 1.5 | 2.93 |

It may be possible to recognize certain features of the search object on the sonar trace, such as deck houses and masts, as shown in Section 8 of this report. Dimensions of the sonar image can be compared to those of the search object in order to increase the probability of identification. In actual Coast Guard practice, a positive identification, i.e., a $P_I$ of 1.0, is not made without visual confirmation of the object by divers or an underwater vehicle. However, as shown in Section 7, a high probability of identification can be achieved by correct interpretation of the sonar image.

The dimensions of the sonar image in the sweep direction, i.e., the lateral direction when looking at the sonar record on the recorder are quite reliable, and are the principal dimensions used in classifying the target. The side scan sonar geometry is explained in the EG&G Manual and is reproduced with slight modification in Figure 14. The height which an object protrudes off the sea bottom ($H_t$) can be determined from the length of the shadow and other parameters which can be measured directly from the sonar trace. Recall that the distance measured from the center line of the sonar trace to an object is the slant range ($R_s$). Then with the length of shadow from the trace ($L_s$) and the altitude of the towfish off the bottom ($H_f$), by similar triangles:

$$H_t/L_s = H_f/(R_s+L_s)$$

the height is found

$$H_t = H_f L_s/(R_s+L_s)$$

At this time it may be appropriate to comment on the best altitude to use for the towfish. There are several points to consider. (1) A low altitude will decrease the blank or water column portion of the sonar record. For this reason the users manuals recommend an altitude equal to 10% of the range scale. (2) A low altitude will increase the vertical profile and acoustic shadow of the object. (3) The detection probability is greater in the vertical center of the beam pattern. This is the best reason to use for selecting the towfish altitude.

The optimal situation is to place the center of the beam pattern at the center of the range setting on the recorder. This is done by towing the towfish at an altitude above the bottom that corresponds to the range setting.

We can compute this optimum towfish altitude from the recorder range setting and the beam depression angle set in the towfish. Referring to figure 14 for the beam to be centered on the recorder

$$R_s = \frac{1}{2} R$$

where R is the recorder range setting. Then from the figure

$$H_{fo} = \frac{1}{2} R \sin\beta$$

where $\beta$ is the depression angle ($10^o$ or $20^o$) and $H_{fo}$ is the optimal towfish altitude.

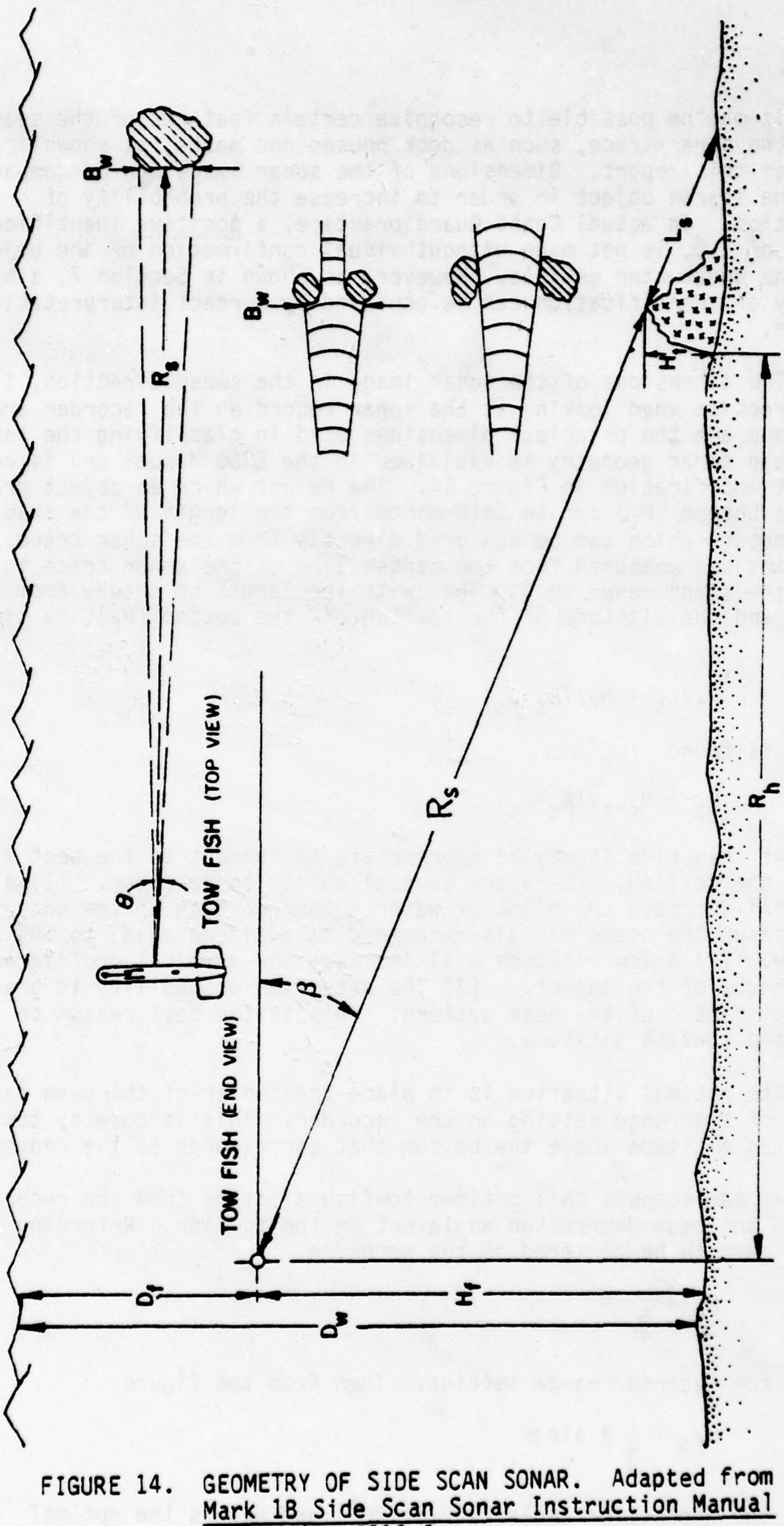



FIGURE 14. GEOMETRY OF SIDE SCAN SONAR. Adapted from Mark 1B Side Scan Sonar Instruction Manual TM73-241C, EG&G Inc.

The dimensions of the image in the track direction, i.e., vertical direction when looking at the sonar record on the recorder are not as reliable since they are related to the towfish speed over ground, which cannot be instantaneously measured. The towfish speed over ground can be measured over a period of time by the navigational system if it is sufficiently accurate, or estimated from the search vessel's speed through the water. The length of the image is also related to the paper feed, and the range scale. The two latter effects can be lumped into a single parameter called the "time scale" as shown in Table 2.

The length of the target in the track direction can be computed as follows:

$$\underset{\text{(meters)}}{\text{length of target}} = \underset{\text{(m/s)}}{\text{towfish speed}} \times \underset{\text{(in.)}}{\text{image length}} \times \underset{\text{(sec/in.)}}{\text{time scale}}$$

Using these techniques for estimating the dimensions of the target in the sweep and track directions, a rough picture of the target can be produced.

TABLE 2. TIME SCALE IN SECONDS/INCH TO BE USED IN COMPUTING LENGTH OF TARGET ALONG TRACK IN THE EG&G MARK 1B MOD 4 SIDE SCAN SONAR SYSTEM

| | Paper Feed (lines/inch) | | |
|---|---|---|---|
| Range Scale (meters) | 200 | 150 | 100 |
| 50 | 13.3 | 10 | 6.7 |
| 100 | 26.7 | 20 | 13.3 |
| 125 | 33.3 | 25 | 16.7 |
| 200 | 53.3 | 40 | 26.7 |
| 250 | 66.7 | 50 | 33.3 |
| 500 | 133.3 | 100 | 66.7 |

## 7.0 IMAGE RESOLUTION

Most commercial side scan sonars, such as the EG&G sonar used in this test, use a frequency of about 100 kilohertz. The propagation of acoustic waves in water is analogous to that of electromagnetic waves in the visual range and therefore the techniques used in classical optics apply to underwater acoustics. With an acoustic frequency of 100 kilohertz and a range of 100 meters, Fraunhofer diffraction theory may be used in which the resolution is shown to be directly proportional to the wavelength of the acoustic sensor by the Rayleigh criterion:

$$D = 1.22 \frac{\lambda}{\Theta}$$

in which D is the minimum distance between two points that may just barely be resolved, $\Theta$ is the acoustic beam width and $\lambda$ is the acoustic wavelength (Fowles). For the EG&G sonar, the minimum distance is just under 1 meter by this method. Thus it is shown that there is less resolution with a larger acoustic wavelengths.

The selection of the acoustic wavelength to use in a side scan sonar system depends upon the application of that system and a compromise must be reached between the image resolution and the desired maximum range and scanning rate. Range and scanning rate are important if the system is to be used in a search mode. The shorter acoustical wavelength signals are more rapidly attenuated by the water by an effect known as acoustic absorption. Acoustic absorption is frequency dependent and is a process in which the acoustic energy is converted into heat by the effects of viscosity, thermal conduction and molecular relaxation. Acoustical absorption along with the usual effect of geometrical spreading may be empirically determined. Selection of the 100 kilohertz frequency shows the use of sweep widths of 1000 meters in searching for large targets at a speed of advance of 1-1/2 meters per second or approximately 5-1/2 kilometers per hour.

### 7.1 Interpretation of Side Scan Sonar Images

A comparison of side scan sonar images of particular cultural objects on the sea floor and those images obtained by use of more nearly geometrically correct imaging systems, such as photography and perspective drawings will determine the effort required to produce geometrically correct images. This effort is usually accomplished by a skilled operator and is called side scan sonar image interpretation. Side scan sonar image interpretation is the art of examining sonar images for the purpose of identifying or classifying objects and judging their significance.

L.D. Farmer of the USCG Research and Development Center has done previous work in the interpretation of side-looking radar imagery (SLAR) by use of basic clues. Since SLAR is the radar equivalent of side scan sonar, his method of interpretation is presented (Farmer). Imagery generally contains many subtle clues as to an object's true identity. Rarely can one single clue be relied upon to provide the correct classification of a target. A careful analysis of all available clues is usually required. Several clues leading to a single conclusion is a much more accurate way of properly identifying a target. There are several basic clues which apply to almost all forms of imagery. These are: size, shape, shadow, tone, texture and pattern. These clues were originally developed by aerial photographic interpretation experts and adapted to other sensors.

SIZE of an object is one of the most important clues as to its identity. By measuring the dimensions of an unknown object on side scan sonar imagery, the interpreter can frequently eliminate from consideration other possible or probable classifications. It is advisable when faced with an unknown object to measure it. It is important to note that the measured dimensions of the object being measured must be greater than the resolution of the sonar at the range to the object in order to be significant. This resolution depends on the acoustic beam width, target range and speed of the search vessel. The height of the object may be computed using the length of the shadow by the method of similar triangles. The time compression effect must be considered when measuring the length of the object.

SHAPE of objects as seen on side scan sonar imagery are often indicative of their acutal shape and nature. The perspective from which the sonar looks at an object greatly affects the shape of the resultant image. The geometrical distortions previously discussed must be considered when determining the acutal shape of an object from a side scan sonar image. Linear features are especially important in identifying man made objects since linear features rarely exist in nature. Most man-made objects are symmetric.

SHADOW. Objects protruding above the sea flor will often exhibit a shadow or no return area behind them. The normal scattering due to the sea floor is blocked out by the object casting an acoustic shadow. Very often the acoustic shadow will exhibit features not seen in the image of the actual object itself. If the side scan sonar transducer is low enough, an exaggerated shadow will be displayed. This exaggerated shadow may show features and details that cannot be seen on the image of the object itself. This may be because the shadow is not affected by diffraction of the acoustic wave by the sharp edges of the cultural object.

TONE. In side scan sonar imagery, objects are distinguished by differing tones or intensity of the print of the image by the recorder. These tones are produced by the varying amount of energy reflected back to the sonar from the object. The amount of enery reflected is dependent upon many of the target properties such as composition, size and the angle of incidence of the acoustic energy to the object. The composition of the target or material of which it is made determines the amount of reflectance of acoustic energy. This reflectance is dependent upon the density of the material and is the best clue as to the composition of the material. Material such as steel has a high acoustic impedance and presents a hard echo on side scan sonar. This hard echo is exhibited by the dark tone of the image.

TEXTURE is defined as tonal repetitions within a single image. Cultural objects are quite uniformly shaped and contoured resulting in uniformly shaped returns of even tone and texture except for one or two abrupt changes resulting from major elements of the structure of the object such as a deck house or large stack on a ship.

PATTERN of an image is the spatial arrangement of the components of an image that is representative of the disposition of the target or targets on the sea floor. This may be an anchor and chain connected to a sunken buoy or the different parts of a shipwreck that has broken up.

Manmade objects on the seafloor are usually symmetrical such as automobiles, boats, and aircraft. This clue may be of value when trying to identify a manmade object.

According to Farmer, the image interpreter must exploit the principle of convergence of evidence to correctly classify objects he had not seen before or does not recognize. There are likely to be many clues to the identity of an unknown object appearing on the side scan sonar imagery, none of which are infallible by themselves as guides to its identity. But if all or most of the clues point to the same conclusion, then that conclusion is probably correct. Side scan sonar interpretation relies on probabilities. Few target classifications are perfectly certain in side scan sonar imagery interpretation but many interpretations are so probable that when all the visible evidence has been considered they may be regarded as correct with a high level of confidence. The difficult part of image interpretation is making judgements of probabilities. In most situations, repetitive images of the object of interest may be taken and, by comparison of the multiple images, the probability of correct interpretation should improve.

## 8.0 IMAGE PORTFOLIO

The major feature of this part is an interpretive portfolio which is a collection of images obtained from selected targets that were placed on the seafloor. These are common targets similar to those that have been the object of actual side scan sonar searches in the past, such as a small airplane, automobile, small boat and a navigational buoy.

The portfolio can be used as a training aid to enable unskilled operators to recognize certain cues in order to identify possible targets.

The portfolio is an arrangement of sonar images of the four targets using different range scales, signal processing modes and target aspect. The images are designated by a code as follows:

1st letter A - aircraft

Target Type B - buoy

C - automobile

D - CG 40 ft. boat

Numerical Code:

Range scale in meters
- last digit of serial number even - SURVEY mode
odd - SEARCH mode

Last Letter B - bow

Target Aspect A - aft

P - port side

S - stbd. side

for example the code C-2001-P would indicate the automobile on the 200 meter range scale using the search mode with a port aspect.

## AIRCRAFT TARGET

The following images are photocopies of sonar traces obtained from a small, single-engine, low-wing aircraft, as was shown in Figure 10, sunk in 25 feet of water. The target is moored to a 2000-pound concrete sinker that simulates the engine which is removed.

The images are the same size as the sonar traces and are oriented as seen on the sonar recorder when the page is viewed the same as this page.

The aircraft target produces interesting images when seen from different aspects or perspectives. As an aid in determining the aspect and range, and evaluating the quality of the image, a small-scale drawing of the aircraft target is shown above the image.

The aircraft is of steel tubular construction covered with 16 gauge sheet metal, and is sitting directly on the bottom. Strong shadows are not apparent in the images of this target because of the light construction and proximity to the bottom. Linear features are apparent in most of the images due to the particular configuration of the target. The aircraft target has a distinct shape and the identification of the image of the target is apparently dependent upon the resolution of the image or the resolving power of the side scan sonar system. Thus not much interpretation is required and the identification probability is directly proportional to the resolving power of the system. In some cases a stronger image is produced by the concrete sinker, as would be expected of a more dense material.

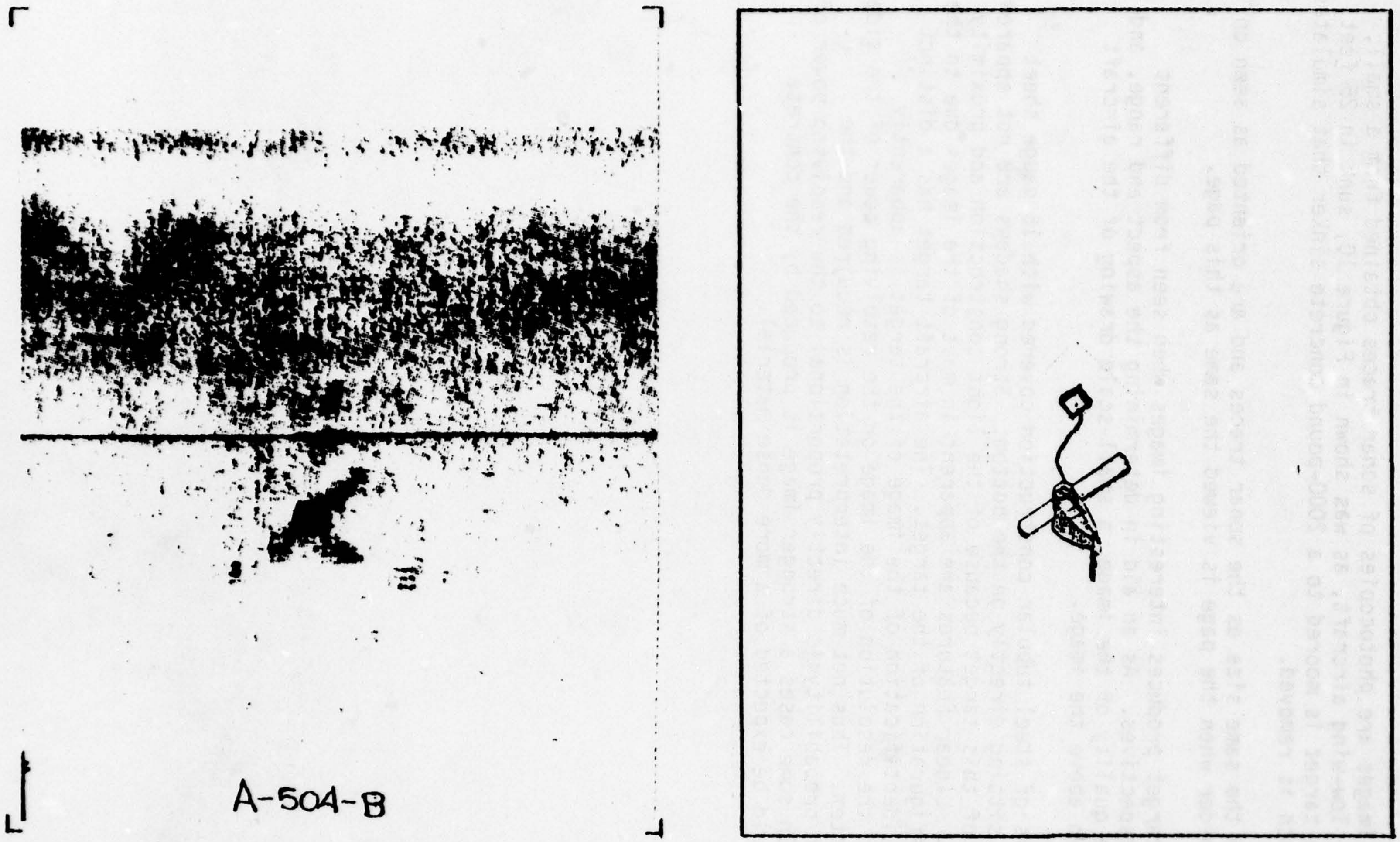
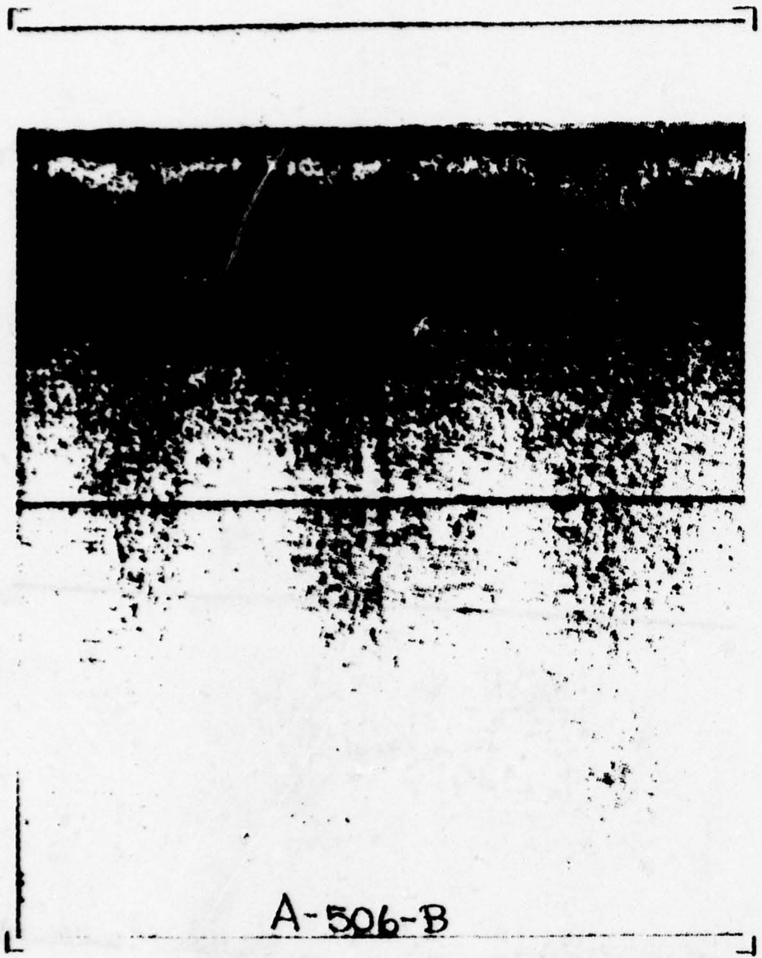



FIGURE 15a.  AIRCRAFT TARGET, 50 METER RANGE SCALE, SURVEY MODE



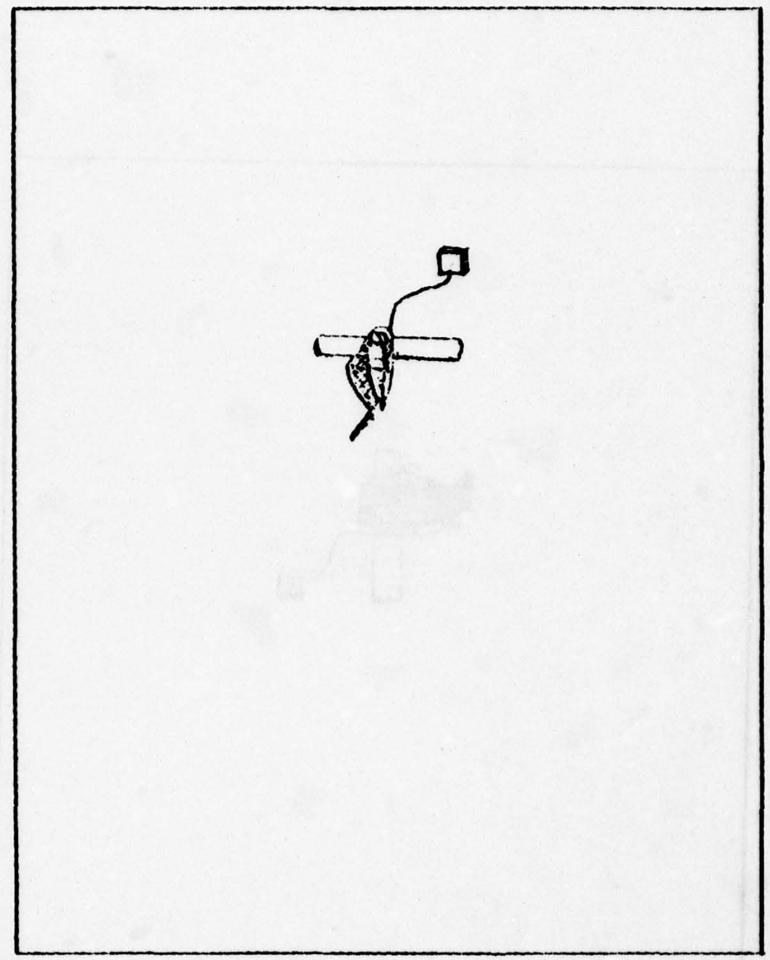



FIGURE 15b. AIRCRAFT TARGET, 50 METER RANGE SCALE, SURVEY MODE

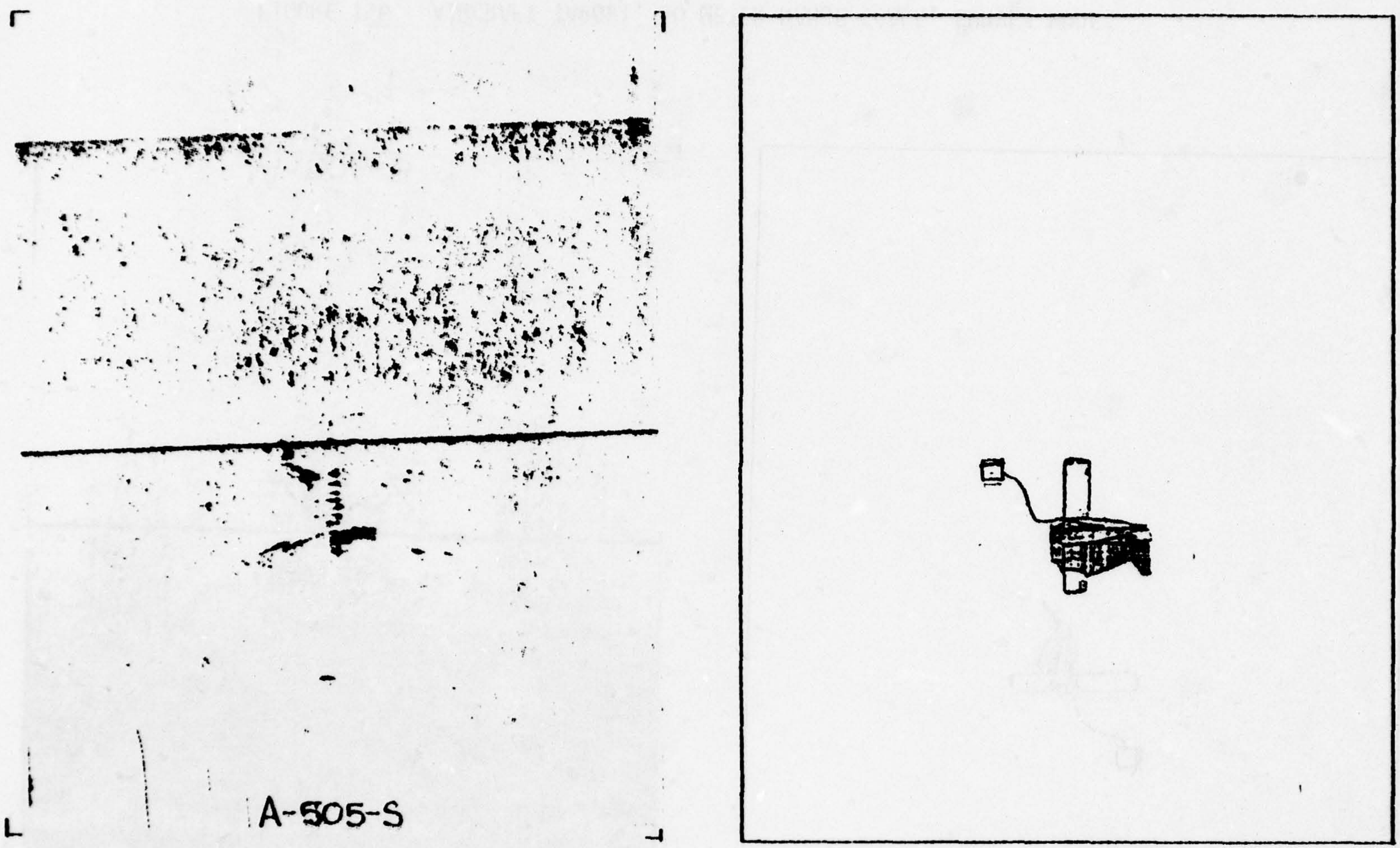



FIGURE 16a. AIRCRAFT TARGET, 50 METER RANGE SCALE, SEARCH MODE

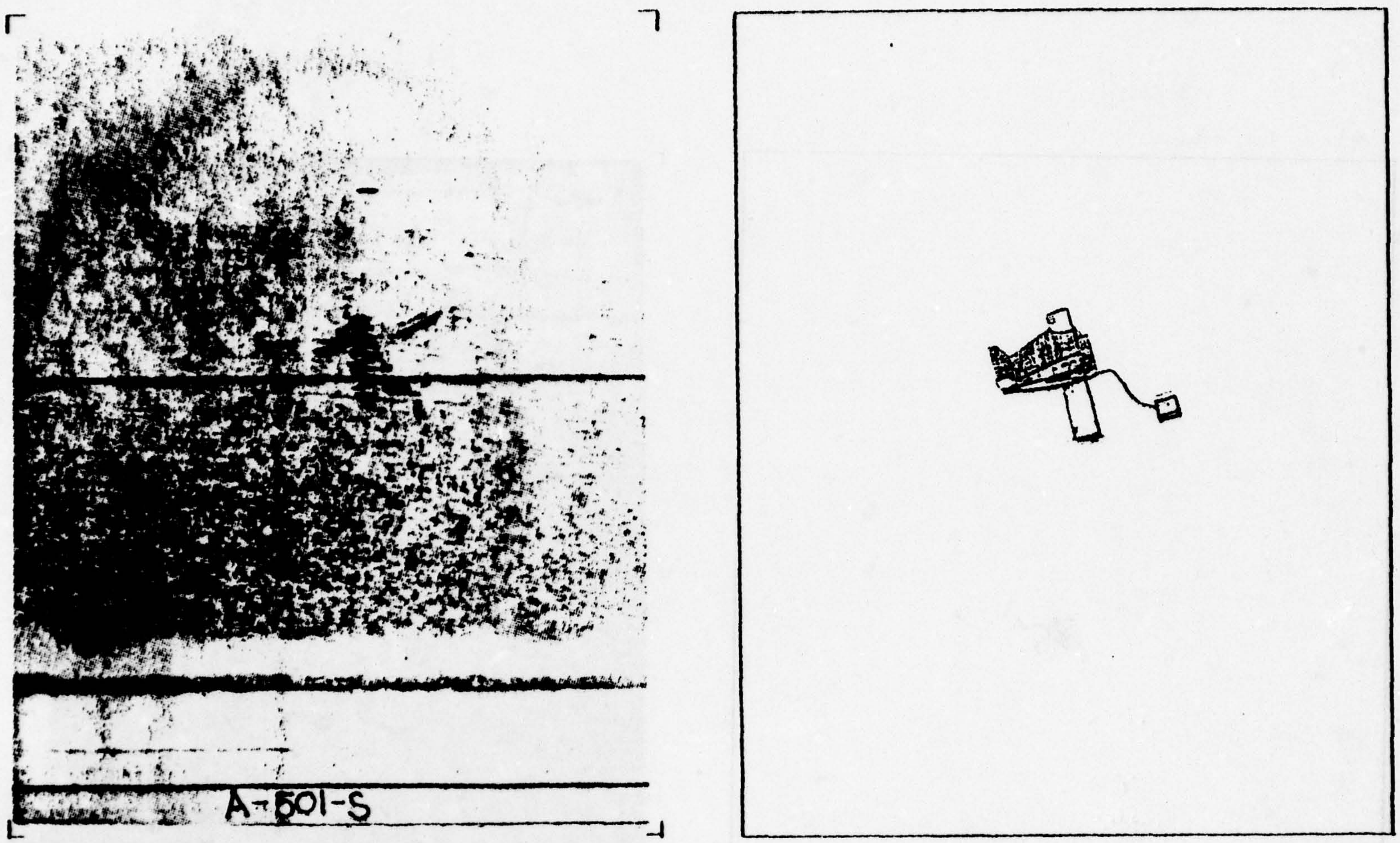



FIGURE 16b. AIRCRAFT TARGET, 50 METER RANGE SCALE, SEARCH MODE

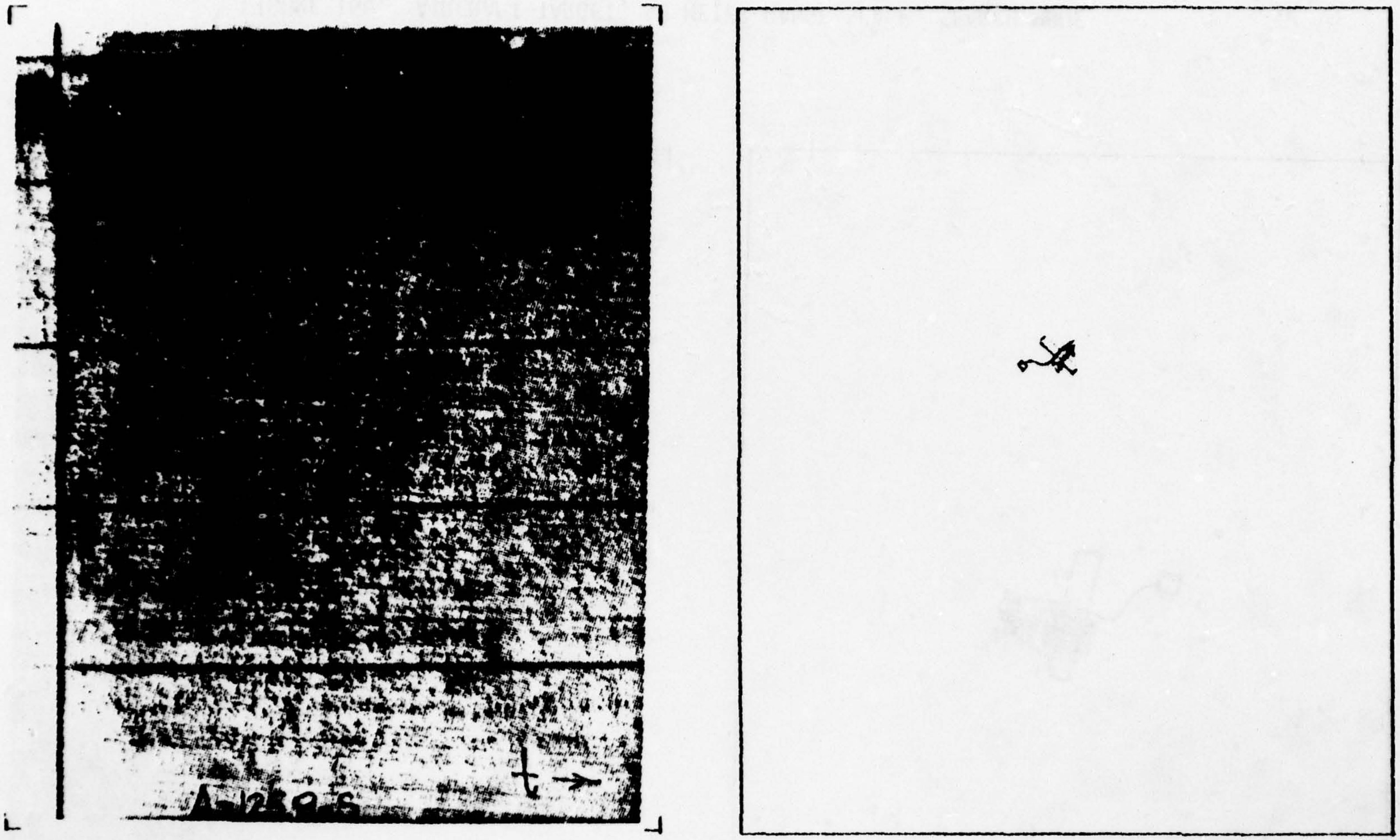
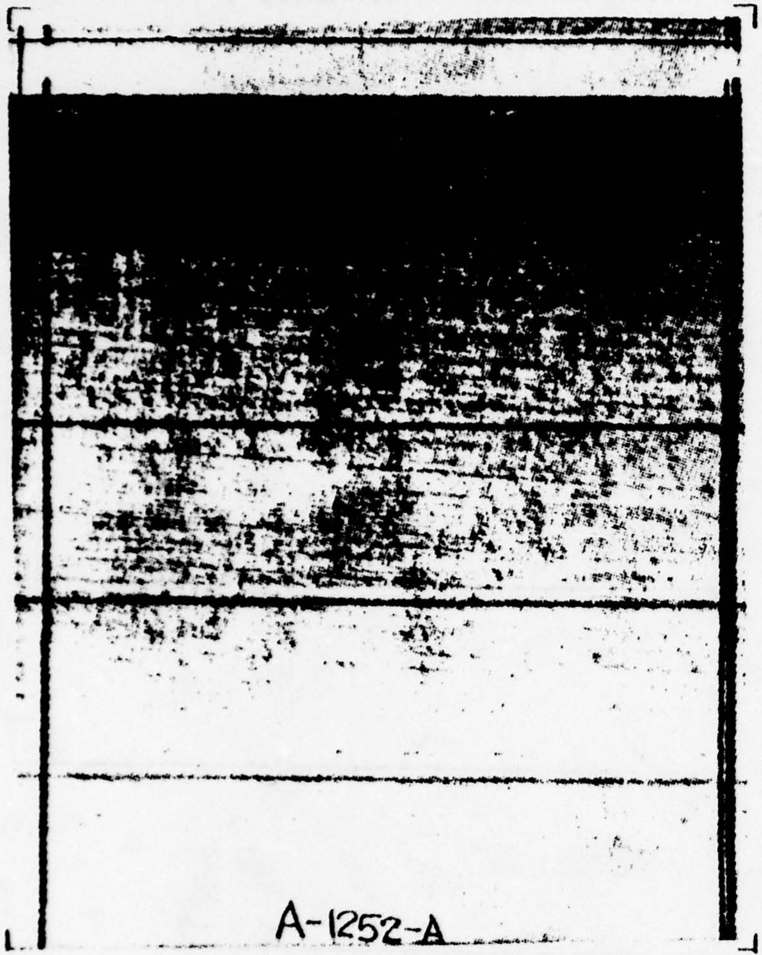


FIGURE 17a. AIRCRAFT TARGET, 125 METER RANGE SCALE, SURVEY MODE



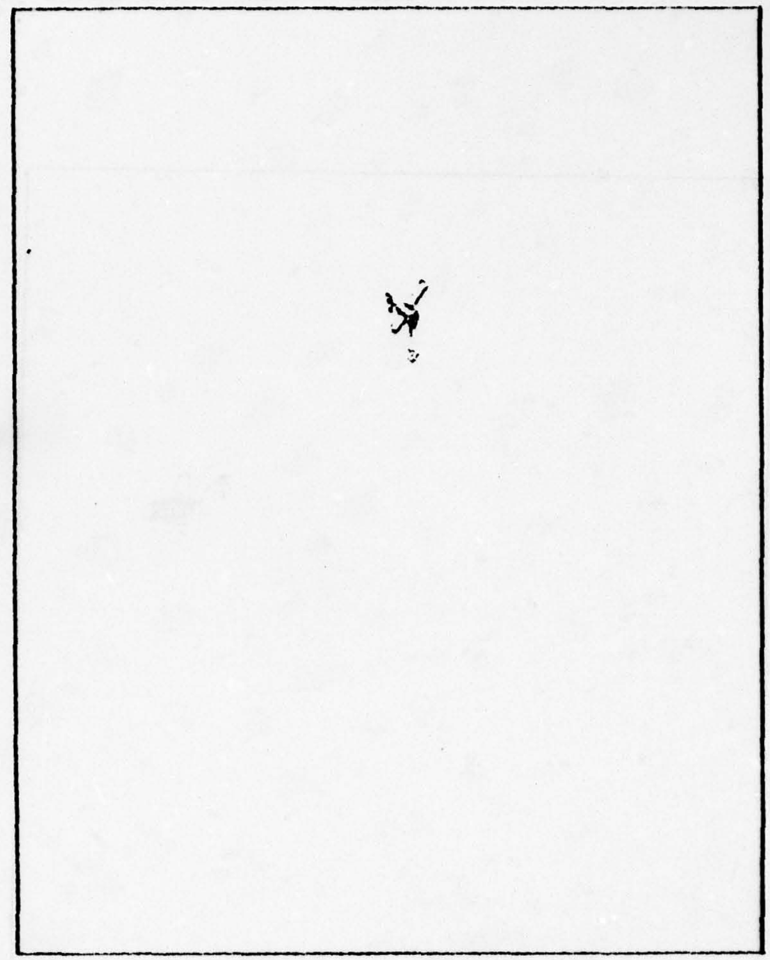



FIGURE 17b.  AIRCRAFT TARGET, 125 METER RANGE SCALE, SURVEY MODE

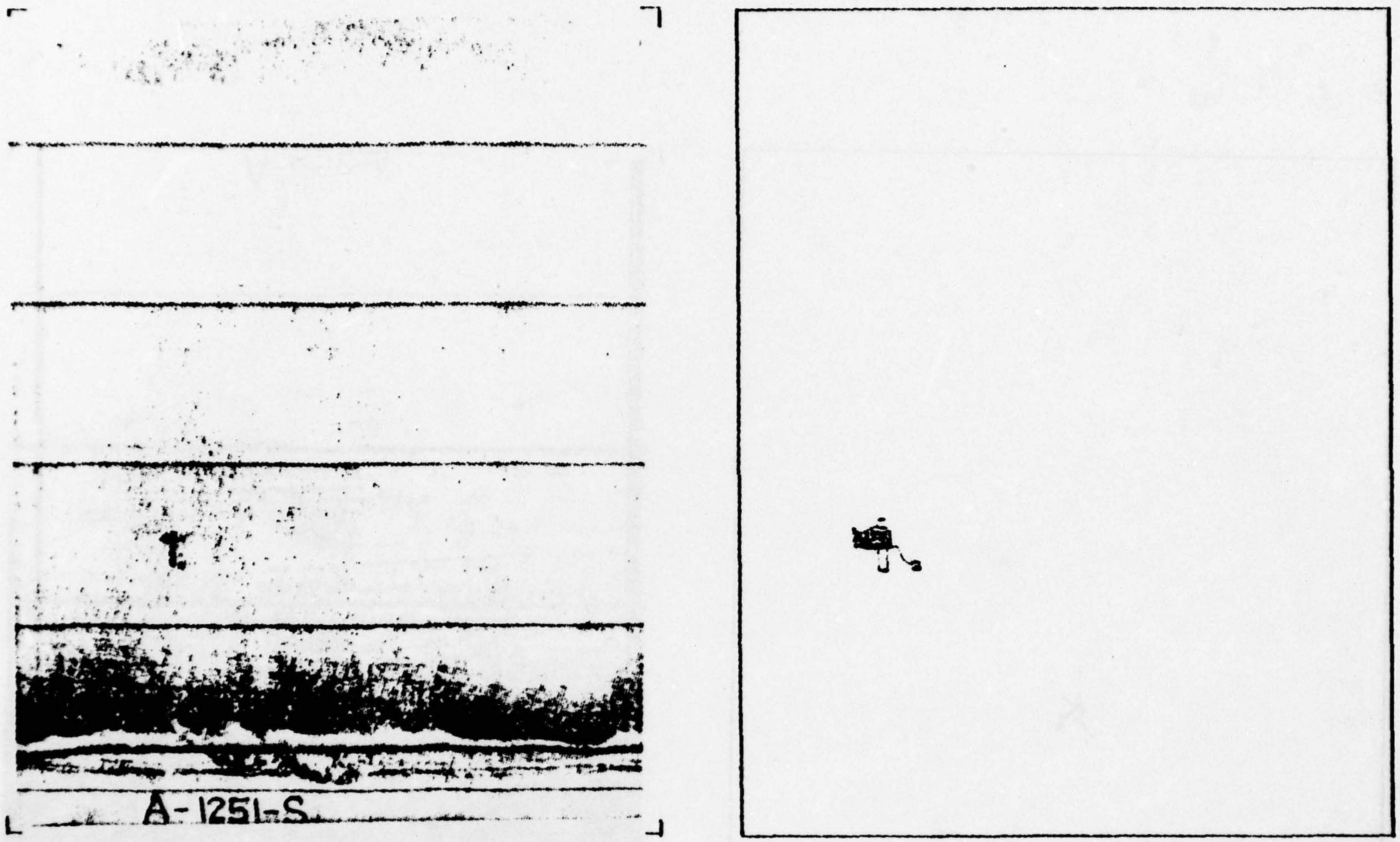
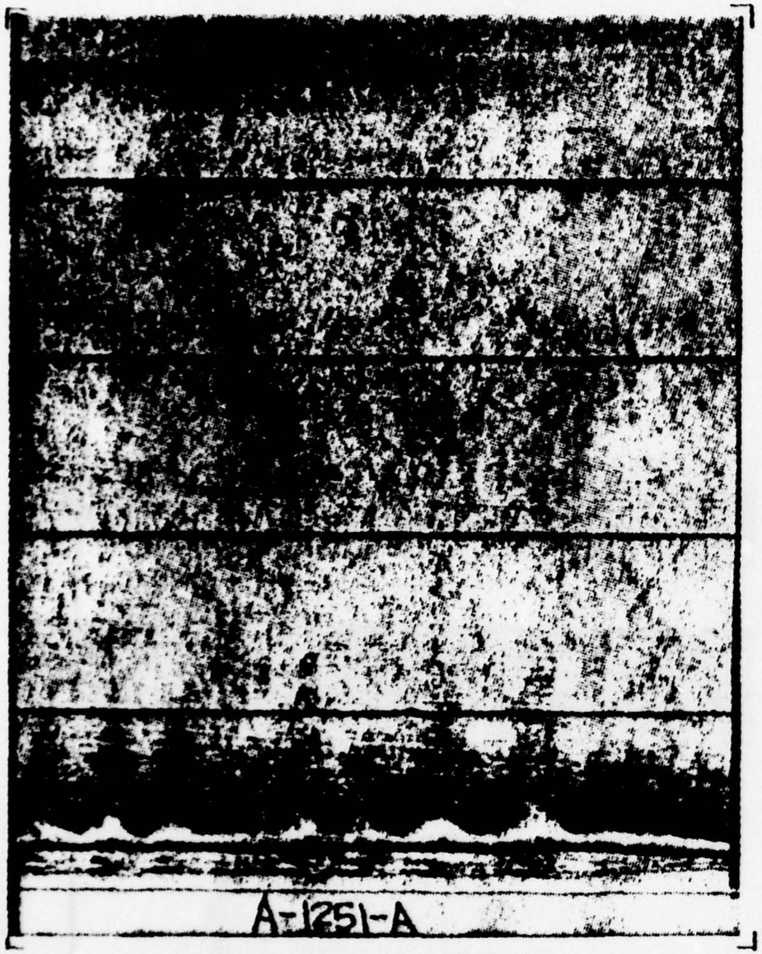



FIGURE 18a. AIRCRAFT TARGET, 125 METER RANGE SCALE, SEARCH MODE



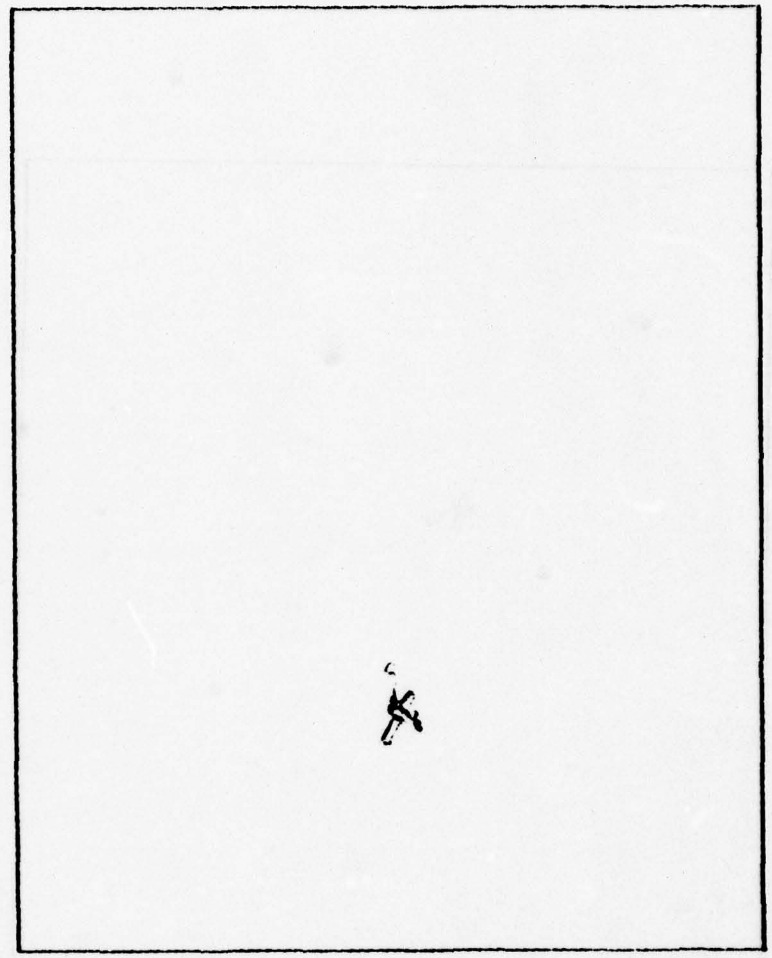



FIGURE 18b.  AIRCRAFT TARGET, 125 METER RANGE SCALE, SEARCH MODE

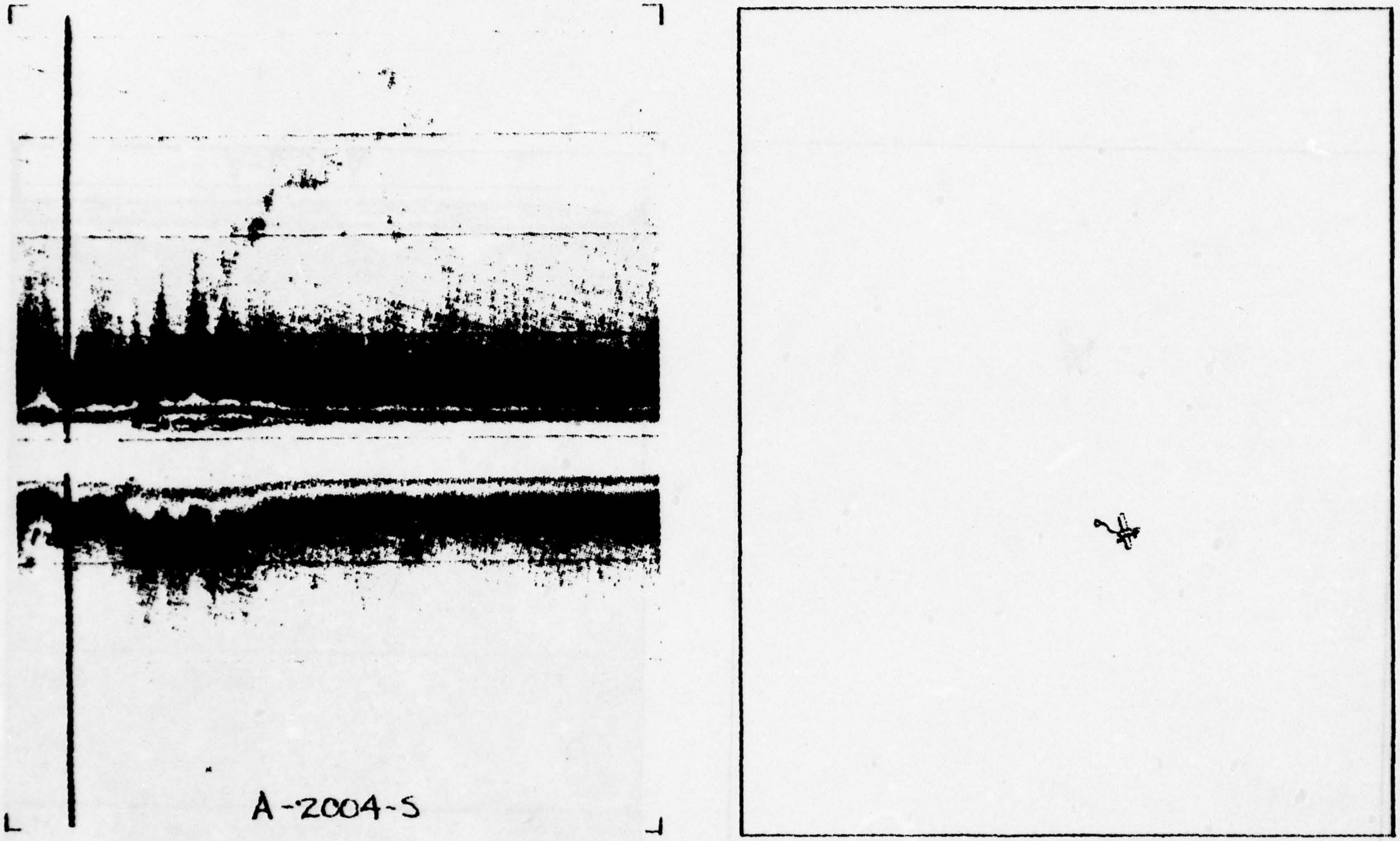



FIGURE 19a. AIRCRAFT TARGET, 200 METER RANGE SCALE, SURVEY MODE

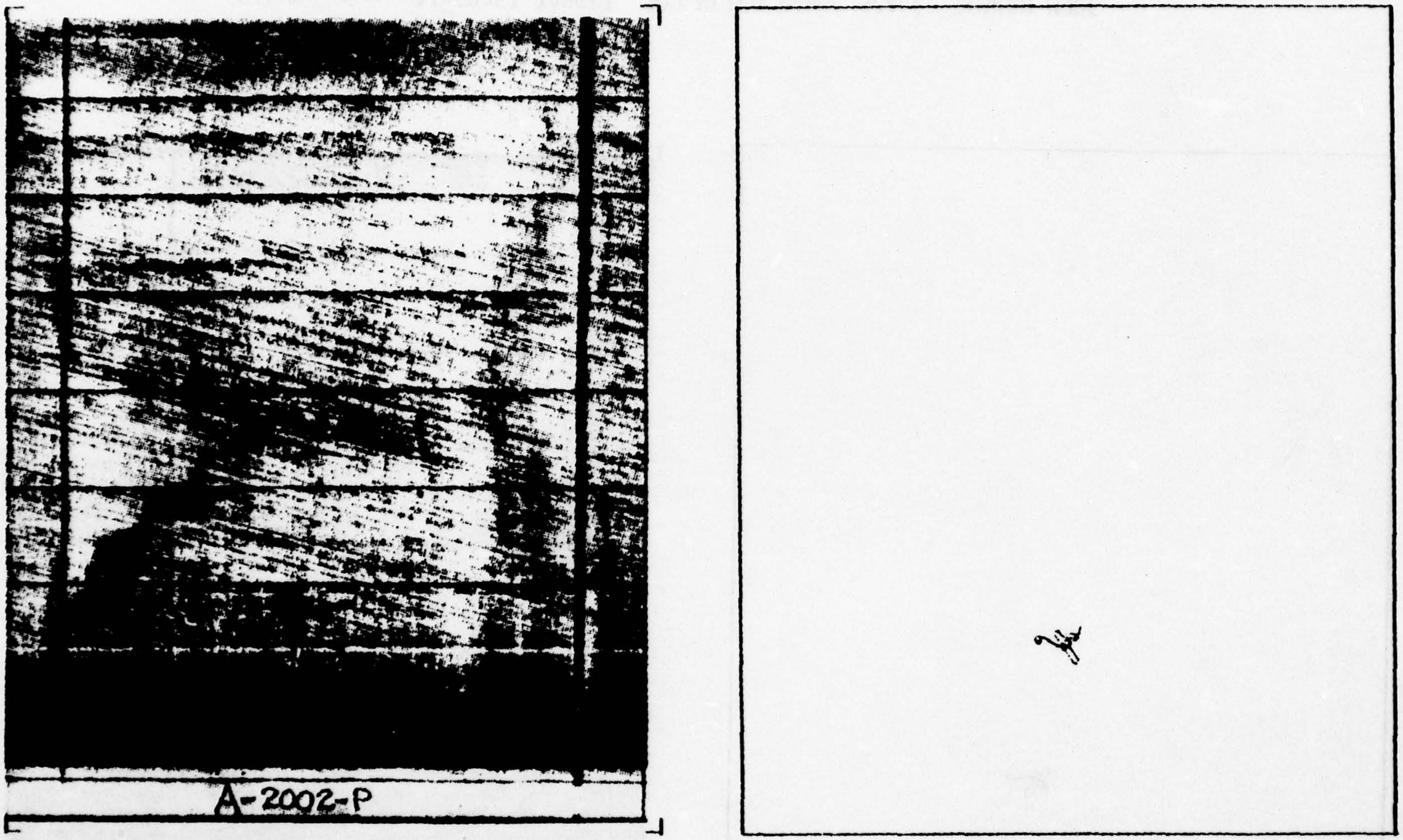



FIGURE 19b. AIRCRAFT TARGET, 200 METER RANGE SCALE, SURVEY MODE

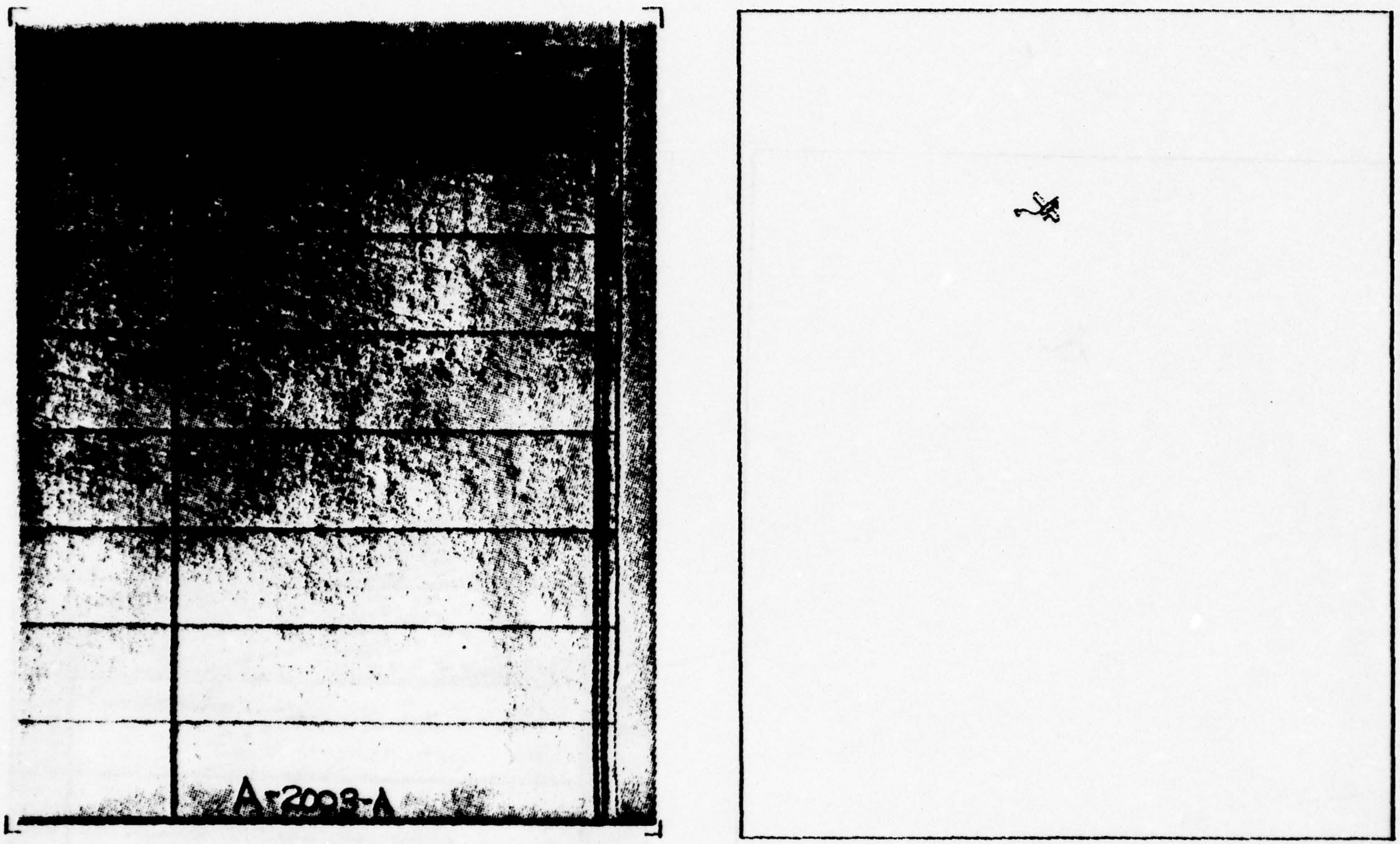
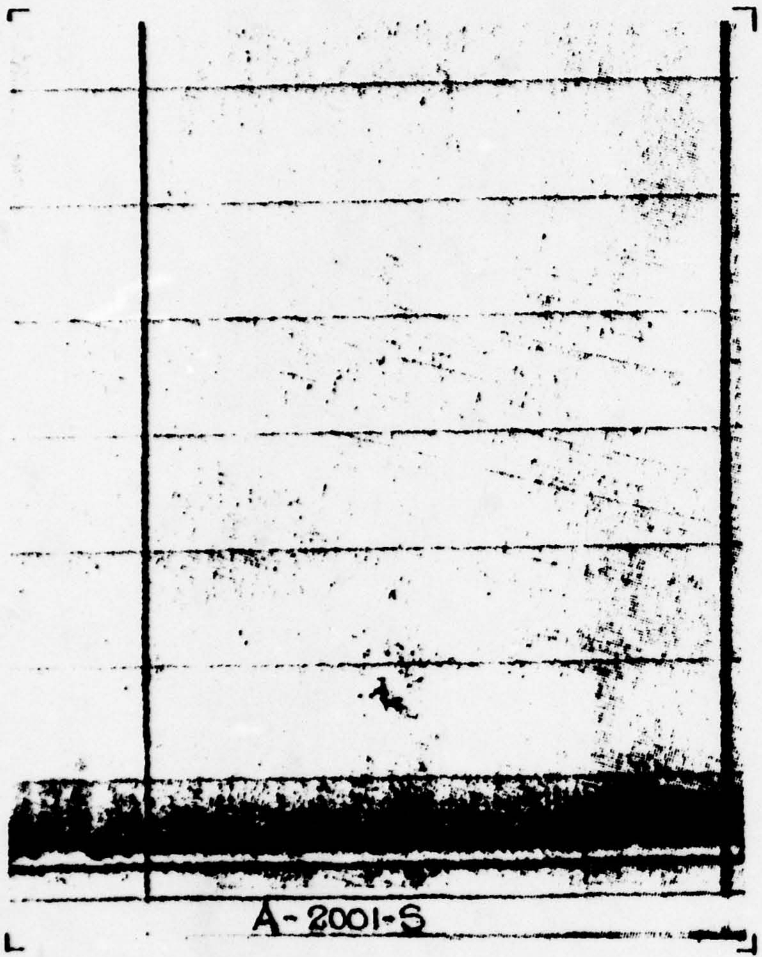



FIGURE 20a. AIRCRAFT TARGET, 200 METER RANGE SCALE, SEARCH MODE



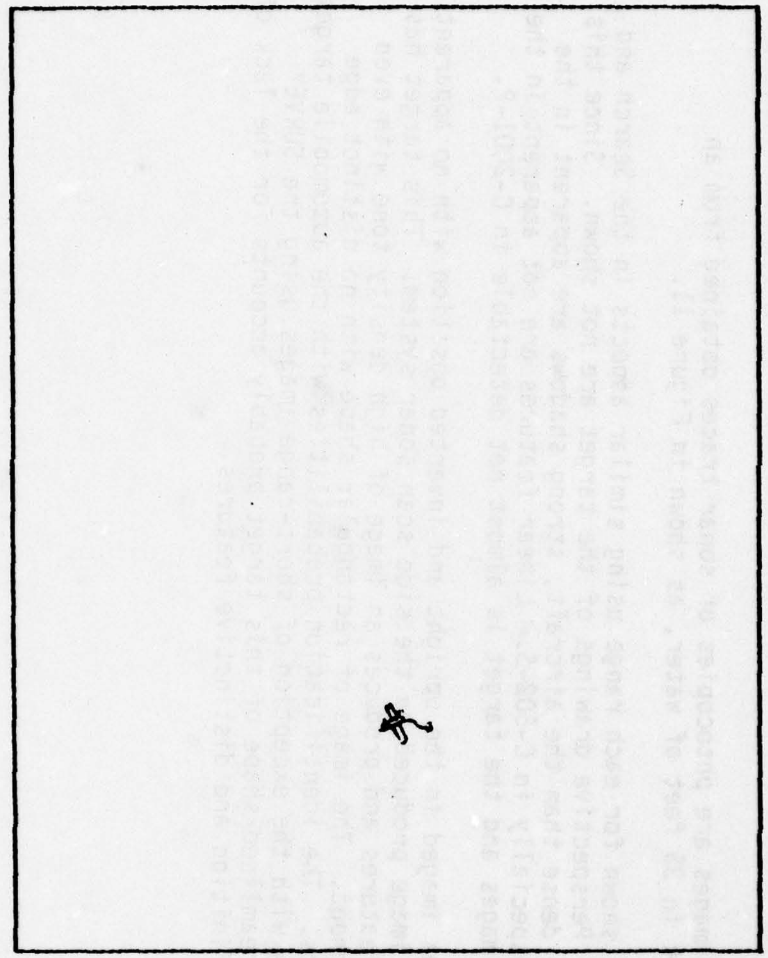



FIGURE 20b. AIRCRAFT TARGET, 200 METER RANGE SCALE, SEARCH MODE

## AUTOMOBILE TARGET

The following images are phtocopies of sonar traces obtained from an automobile sunk in 35 feet of water, as shown in Figure 11.

Two images are shown for each range using similar aspects in the Search and Survey modes. Perspective drawings of the target are not shown. Since this target is more dense than the aircraft, strong shadows are apparent in the Survey Mode, especially in C-502-S. Linear features are not apparent in the longer range images and the target is almost not detectable in C-2001-P.

This target was imaged in the upright and inverted position with no apparent change in the image produced by the side scan sonar system. This target has no prominent features and produces an image of high density tone with even texture throughout. The image of rectangular shape with no distinct edge characteristics. The identification probabilities with the automobile target are fairly low with the exception of short-range images using the SURVEY mode. The streamlined shape of this target probably accounts for the lack of sharp-edge definition and distinctive features.

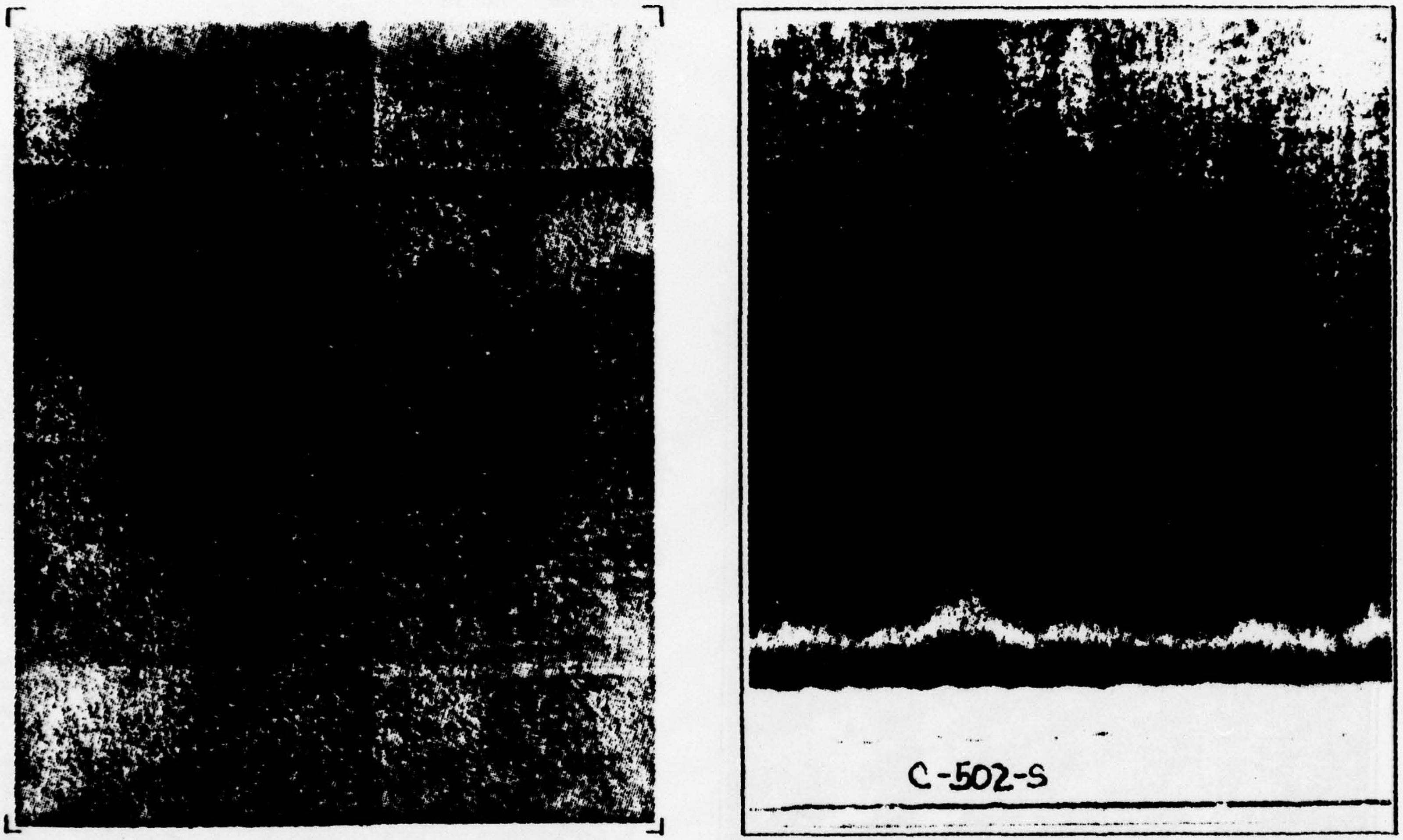
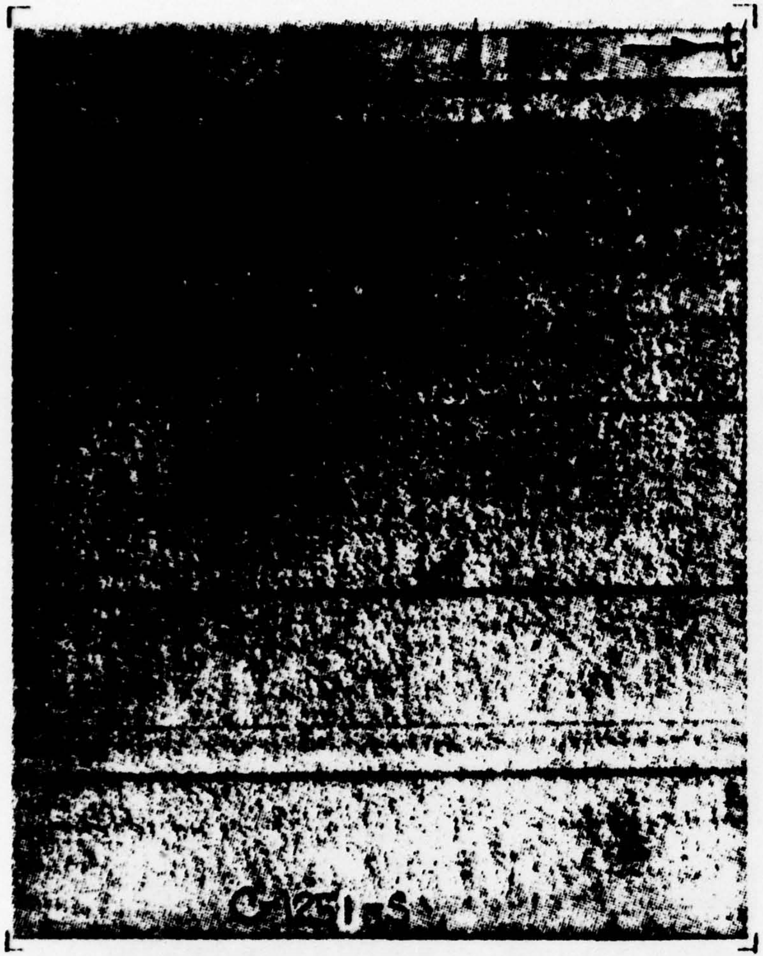



FIGURE 21. AUTOMOBILE, 50-METER SCALE



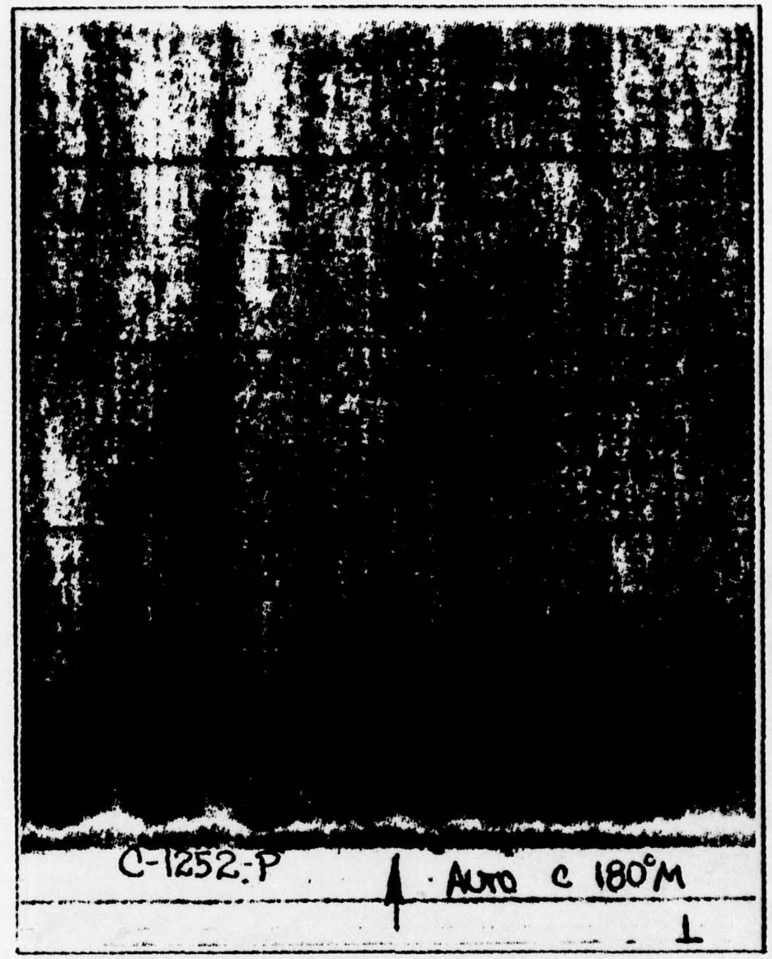
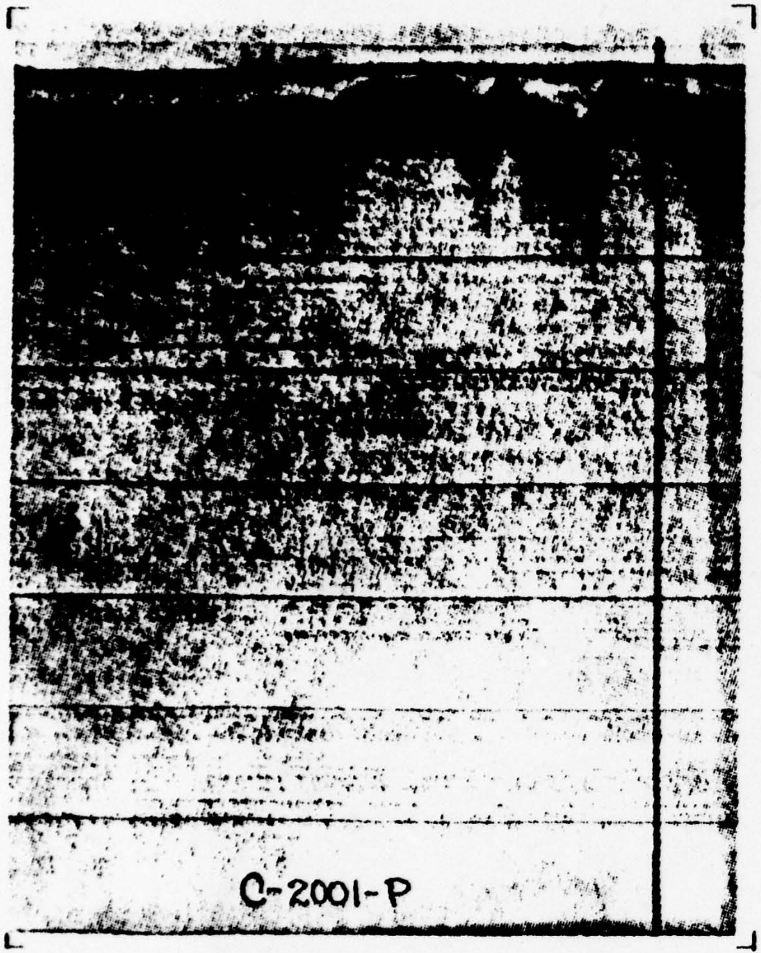



FIGURE 22. AUTOMOBILE, 125-METER SCALE



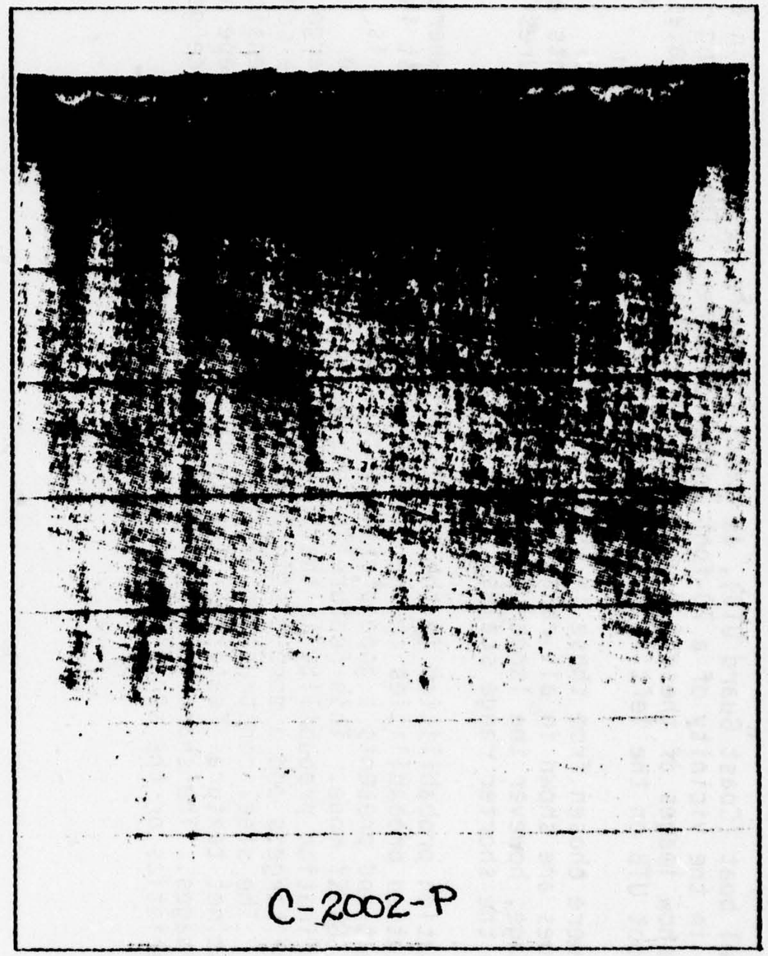




FIGURE 23. AUTOMOBILE, 200-METER SCALE

## 40-FOOT STEEL BOAT

A 40-foot steel boat (Coast Guard UTB), as shown in Figure 12, was sunk in 60 feet of water in the vicinity of a 70-foot wooden schooner. The following sonar traces show images of these two vessels in the 50 and 100 meter scales with the 40-foot UTB on the left.

These traces were chosen from those in which the images are identifiable. Good shadow cues are shown in all range scales. The steel vessel presents a more dense image, however the larger wooden vessel presents linear features especially in the shorter range scales.

The identification probabilities in the SURVEY mode are uniformly high whereas the identification probabilities in the SEARCH mode are low. This target is sitting upright and presents a good profile with a distinct shadow that is shown in the SURVEY mode. This feature is considered to account for the higher identification probability in the SURVEY mode. This target is larger than the other targets and a more distinct image is produced by the side scan sonar system. The steel construction of the vessel presents a medium density tone with distinct textural features. The cabin produces a distinct shape in some of the images. The sharp corners of the cabin and deck area produce good edge characteristics on the sonar images.

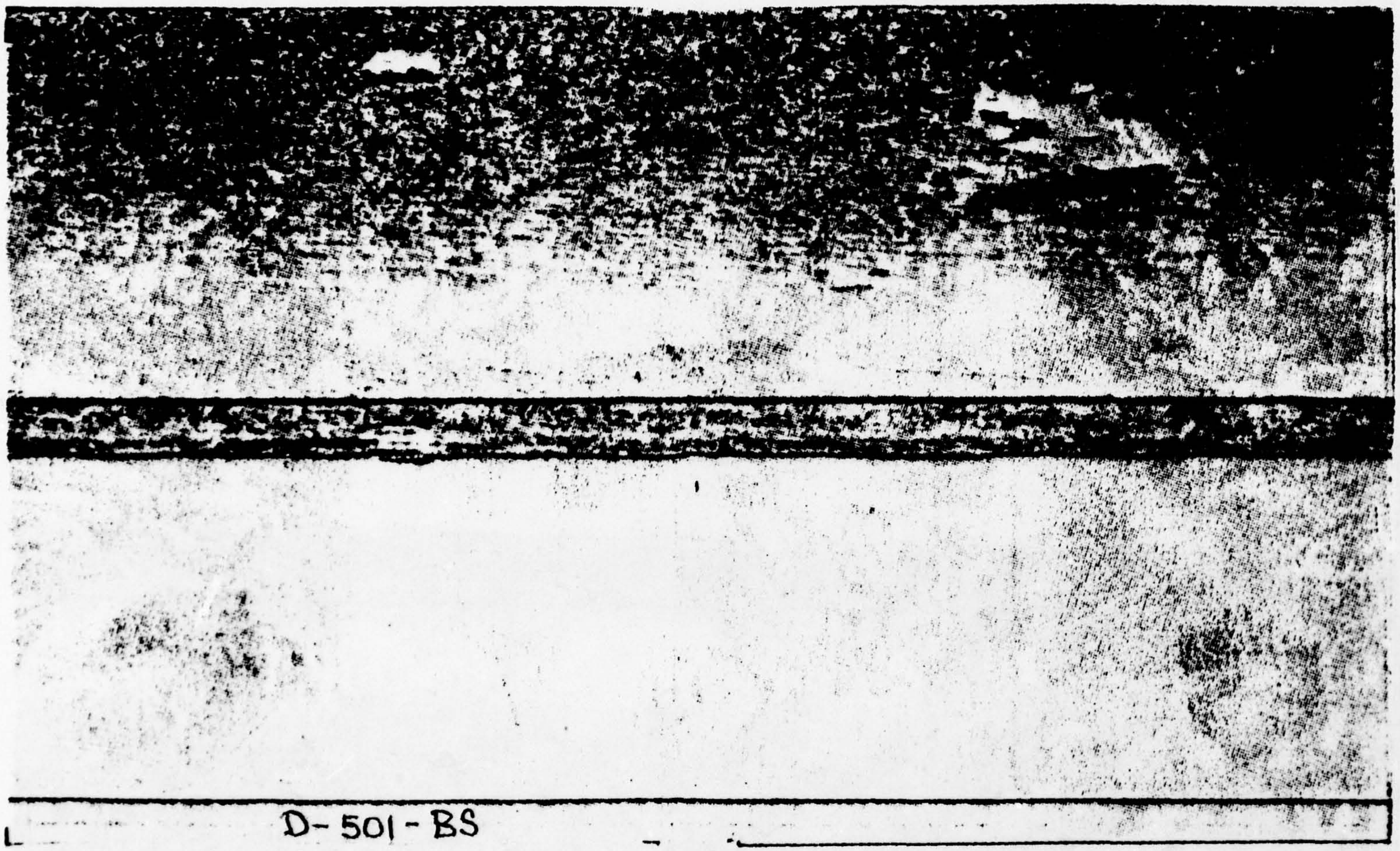



FIGURE 24. 40-FT STEEL BOAT, 50-METER SCALE, SEARCH MODE

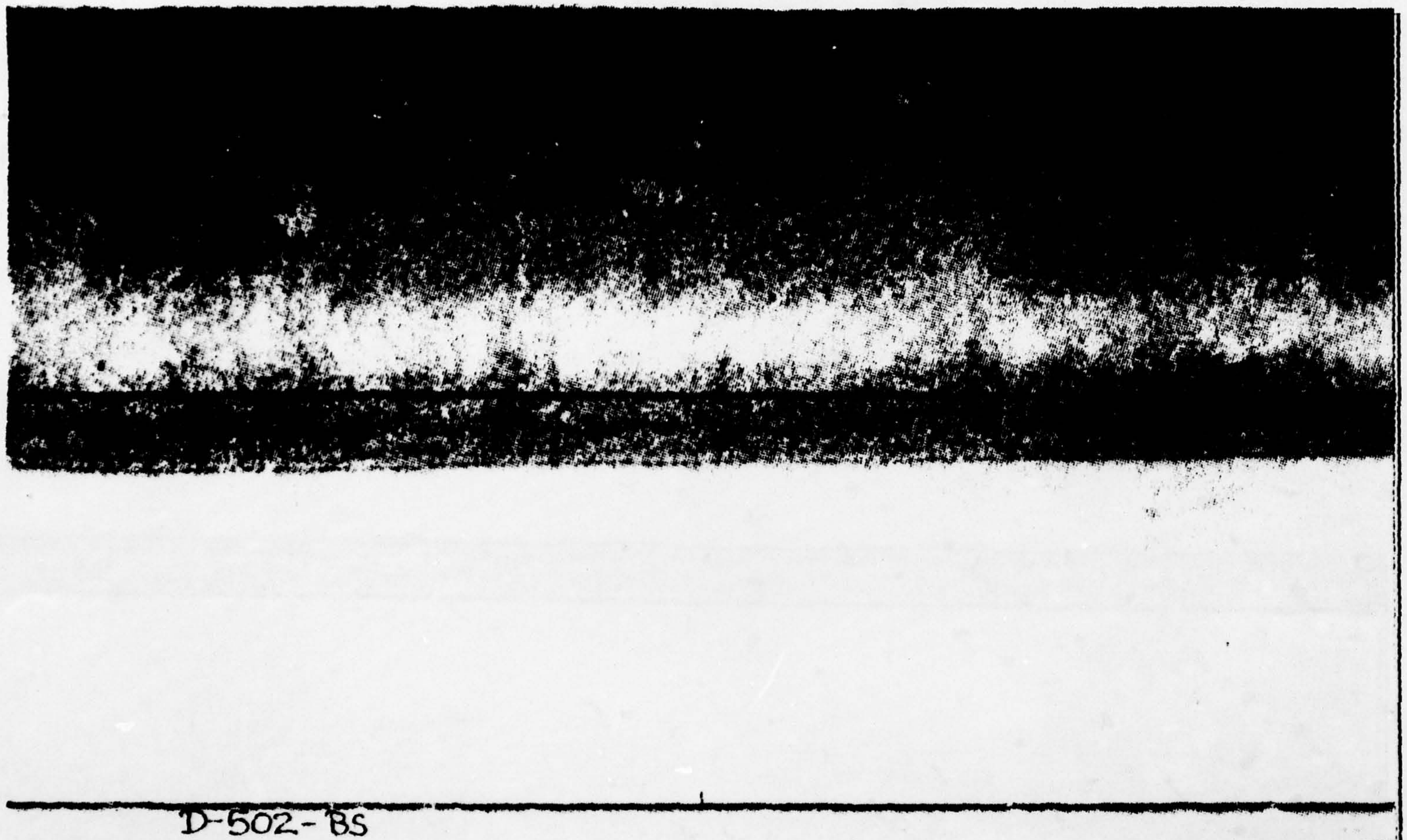



FIGURE 25. 40-FT STEEL BOAT, 50-METER SCALE, SURVEY MODE

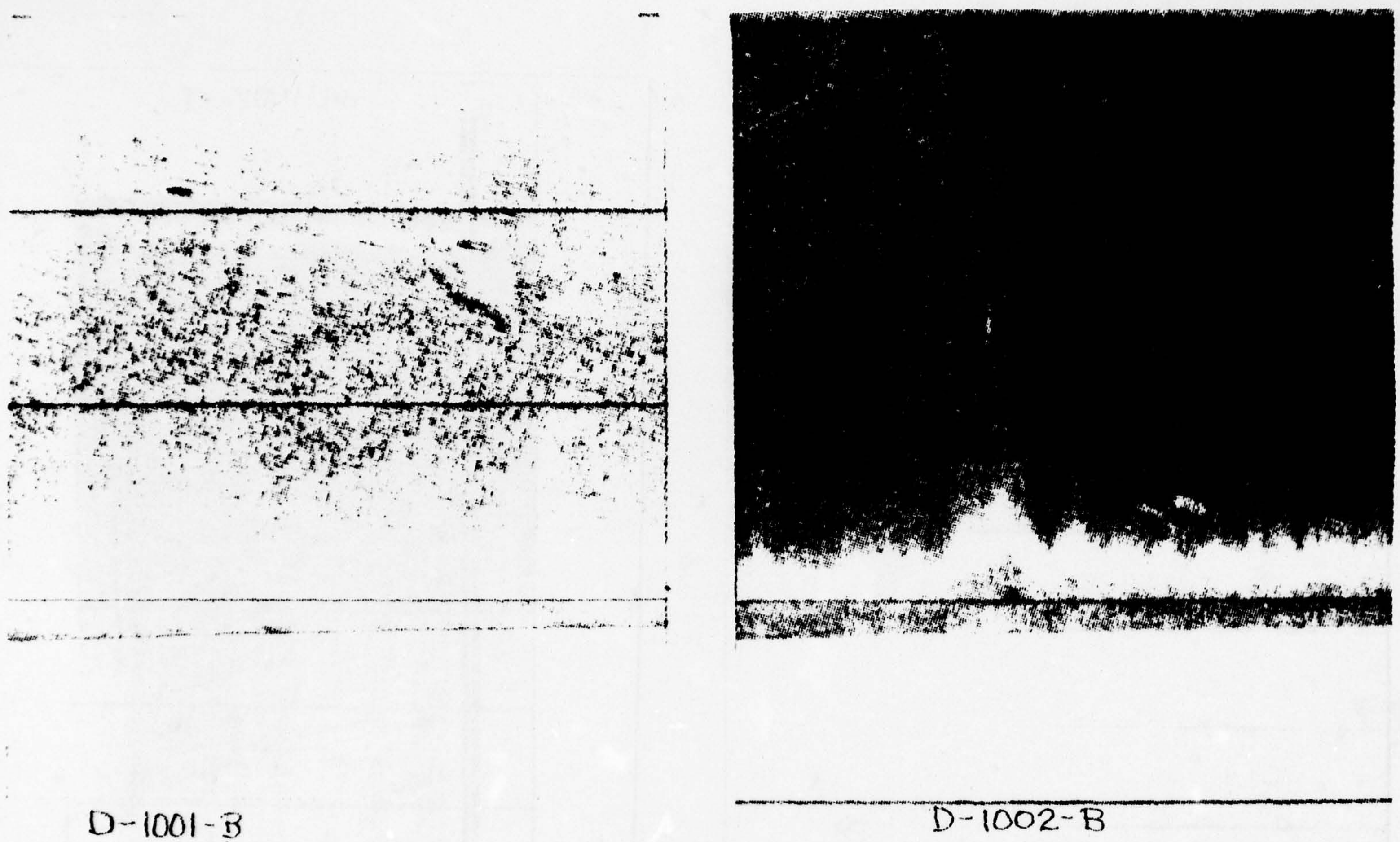



FIGURE 26. 40-FT STEEL BOAT, 100-METER SCALE

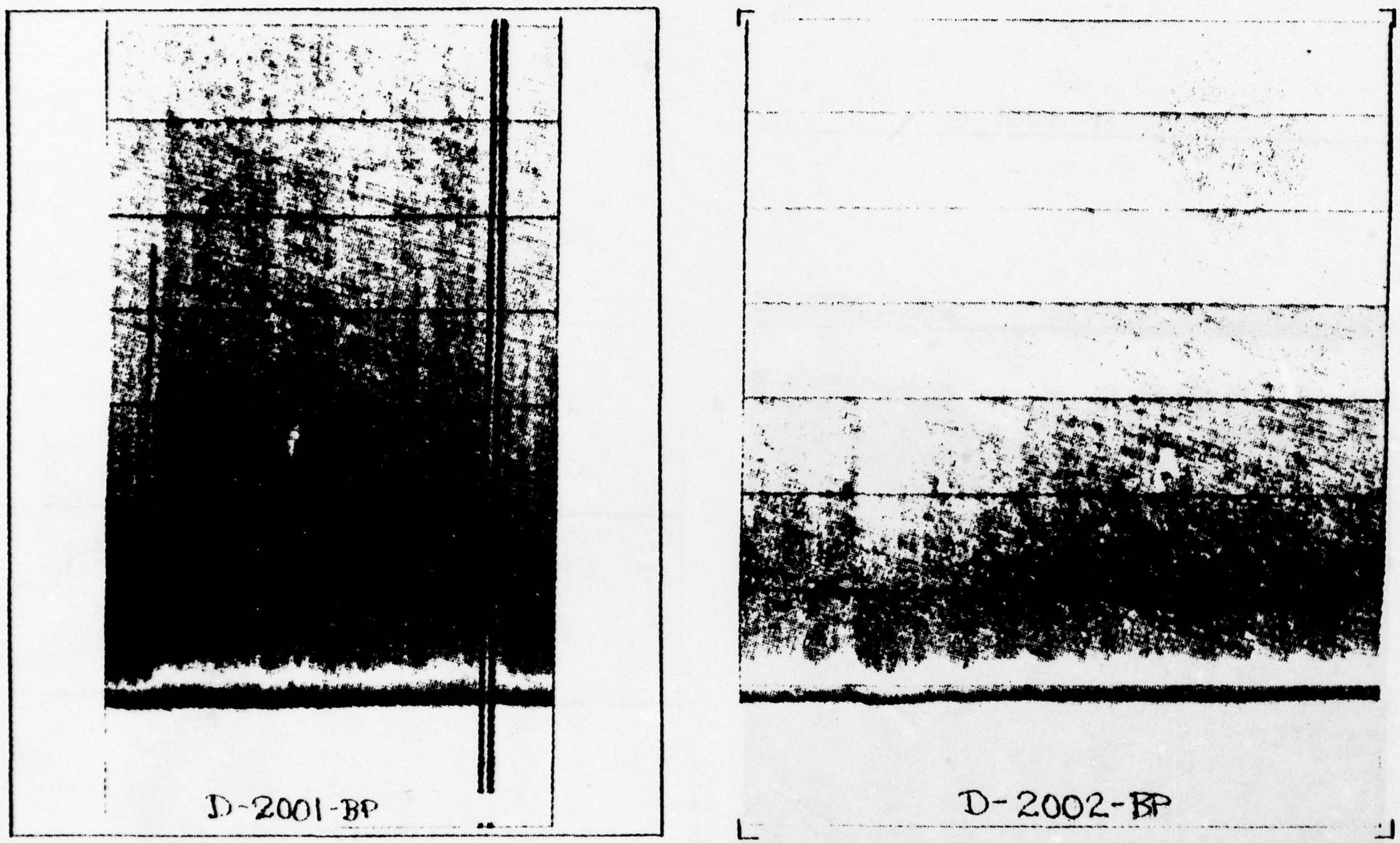



FIGURE 27. 40-FT STEEL BOAT, 200-METER SCALE

## 2NS BUOY

A Coast Guard 2nd Class Nun (special) with 2000-pound concrete sinker and chain, as shown in Figure 13, was sunk in 25 feet of water. In general the buoy was not detectable using range scales greater than 125 meters. The following sonar traces were taken using the 50 and 100 meter range scales.

Shadows and linear features are not apparent. The objects on the bottom present a dense mass of an unusual configuration which is the only cue that can be used.

This target was not detectable at ranges greater than 125 meters. The probabilities of identification are approximately the same for the SEARCH and SURVEY modes. The identification probabilities increased with decreasing range. The most distinctive feature of the image produced by this target was a pattern produced by the two dense objects and the chain connecting them. The individual components of the image were small and did not have a distinct shape or tone. Since the target was lying on the bottom, no shadow was produced.

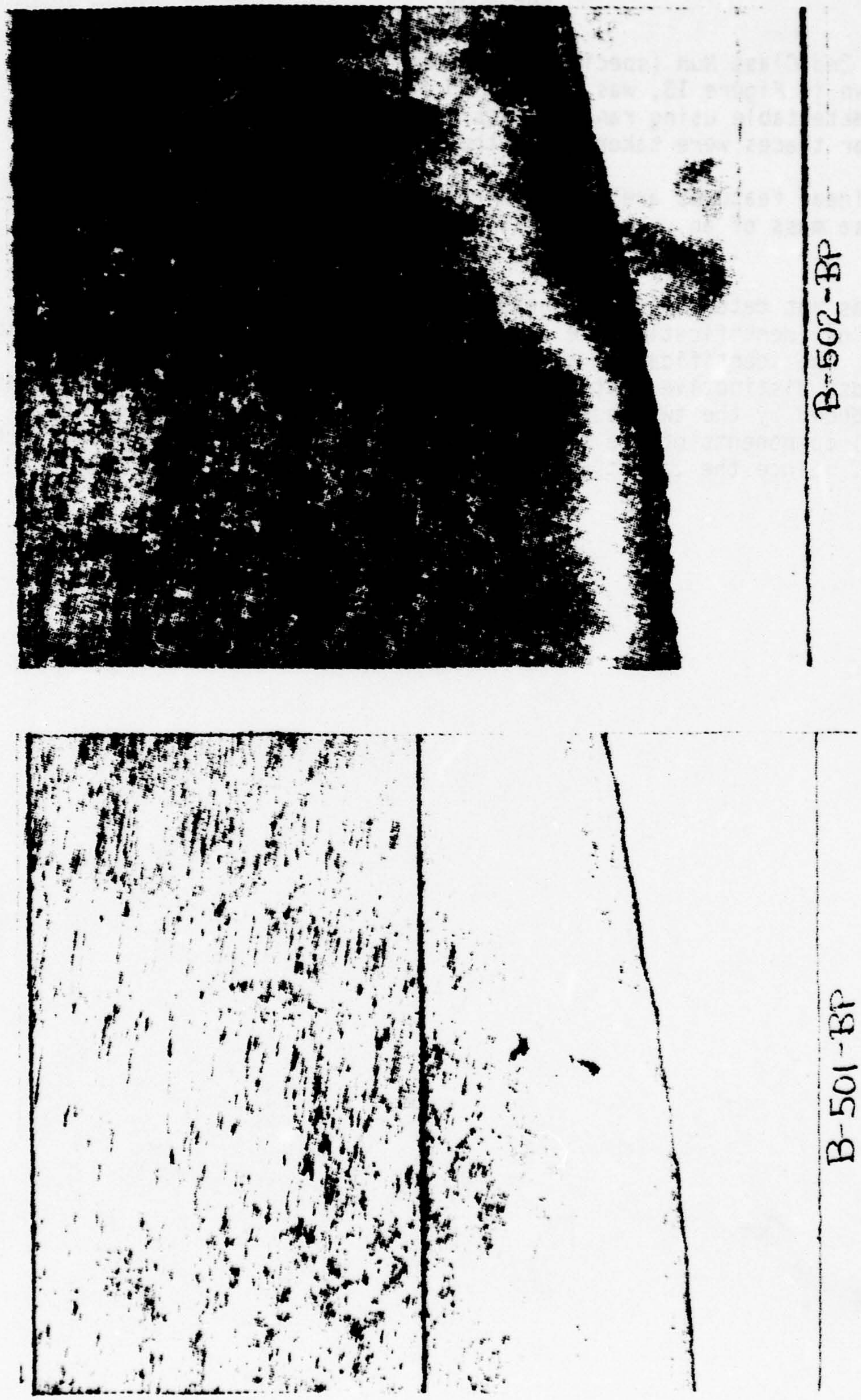



FIGURE 28. "2NS" BUOY, 50-METER SCALE

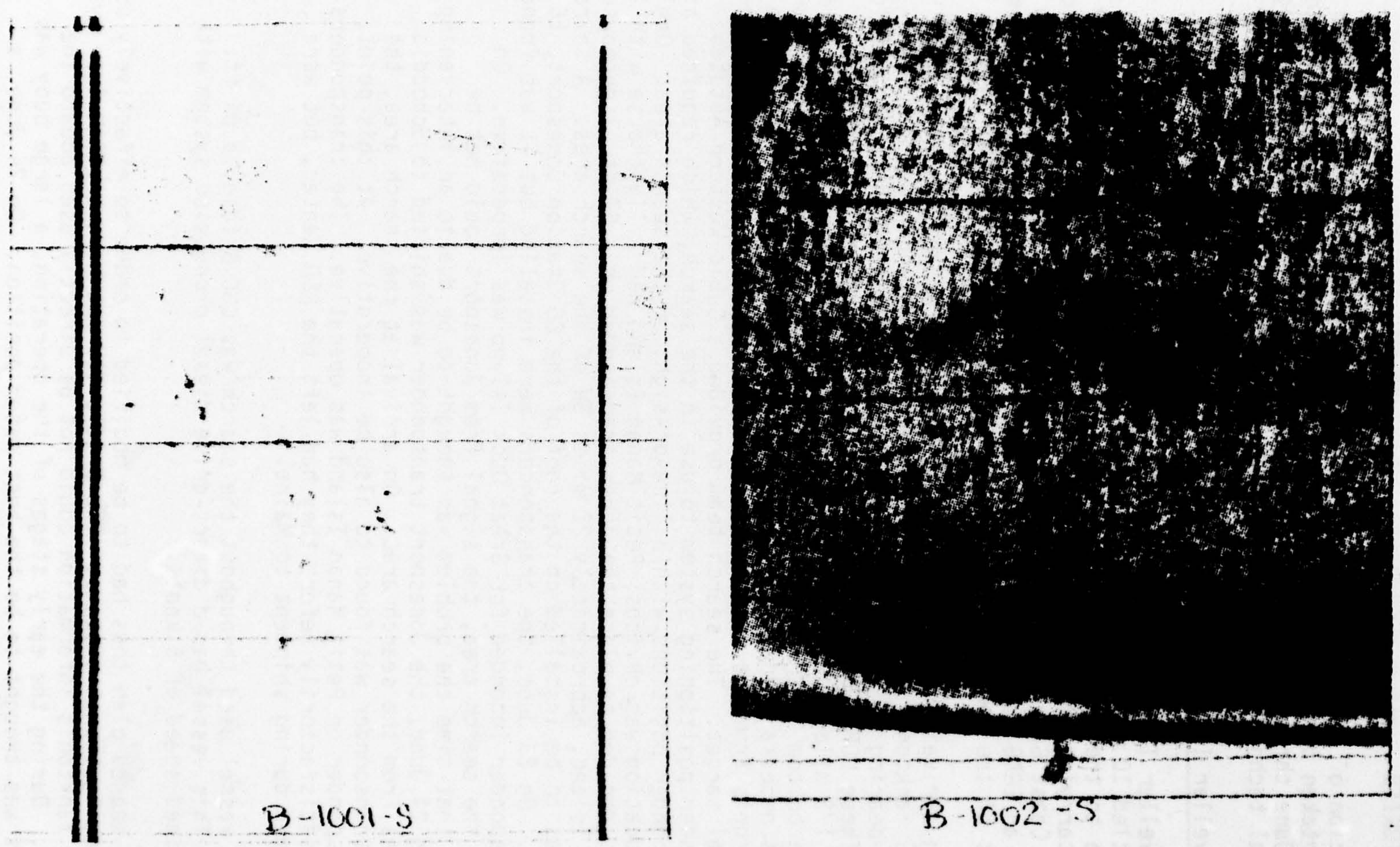



FIGURE 29. "2NS" BUOY, 100-METER SCALE

## 9.0 CASE HISTORIES

This section of the report contains the case histories of 2 underwater searches undertaken by the Coast Guard Research and Development Center during the period 1 June through 31 December 1978, with emphasis on search planning and operational techniques used during each search.

### 9.1 Traveller III

Traveller III is a 61 ft. auxiliary ketch of wooden construction that was scuttled 10 miles off the coast of Maine on 10 June 1978 in 230 ft. of water. Due to the circumstances of the sinking, the vessel was strongly suspected of carrying contraband cargo. On 22 June, a side scan sonar search team from the Coast Guard Research and Development Center was dispatched to the area with an EG&G Side Scan Sonar System for underwater search operations, at the request of the Commander, Coast Guard Group Southwest Harbor, Maine.

Upon arrival intelligence was gathered concerning the sinking incident. CGC Yankton had observed the actual sinking and noted 2 LORAN-A lines, a gyro-bearing to Petit Manan Island 4 miles away and a water depth of 39 fathoms. These LOPs were plotted on a chart and yielded a datum area approximately 1/2 mile square, centered at a depth of 30 fathoms. The chart showed the sea bottom in the area to be very irregular and rocky. Precision navigation was necessary under these conditions in order to account for the many false targets from the bottom and the expected poor quality of the signal from the actual target. The search team provided a Cubic Western Autotape radio transponder positioning system to use in the search, which required at least 2 transponder positions within line-of-sight of the search area. One transponder location was obvious; Petit Manan Island had a lighthouse with AC power. It was decided to place the other transponder on a 67 ft. lighthouse on Great Duck Island, approximately 22 miles SW of the search area. A third transponder was to be installed on the roof of the CG Station Jonesport, 16 miles distant. On 23 June, the transponders were installed but it was found that the transponder intended for Great Duck Island was inoperative. On proceeding to the search area, the signal from Jonesport could not be received. At that time the problem was thought to be due to an intervening land mass. On 24 June, the Jonesport transponder was shifted to Schoodic Point, 12 miles from the search area. On arrival at the search area, the Schoodic Pt. transponder was found to also be inoperative. At this point, only one transponder on Petit Manan Island was operative. The transponders had operated satisfactorily before they had left the R&D Center, but were probably damaged during shipment to Maine.

The vessel used throughout the search was CGC Bridle, a 64 ft. coastal tug. This vessel has a direct-drive diesel propulsion system with a minimum sustained speed of 5 knots.

The search plan thus had to be modified in order to effectively use the existing navigational systems. The Bridle did not have a LORAN-A or gyro compass, thus Yankton's information could not be directly used aboard the search vessel. During the early stages of the operation, a large buoy was placed at what was thought to be the best datum position. On 24 June, a 6-hour sector search using 2 mile legs, 5 degrees apart was conducted using

the datum buoy as a reference and 2 possible targets were found. There was difficulty in keeping the datum buoy in sight due to fog.

On 25 June, a parallel line (PSA) search pattern was set up using the range to Petit Manan Island and the datum buoy. Due to the disparity between the depth of water at the datum buoy and that reported by Yankton, the target was thought to be to seaward of the datum buoy. A 3/4 by 3 mile search area was set up using the visual range created by the datum buoy and Petit Manan as the mid-line. The 200 meter range scale with a 150 meter track spacing was used. 10 hours of search produced 8 possible targets.

On 26 June, the search was continued, however, the towfish snagged a lobster pot warp and the tow cable was damaged. Temporary repairs made to the cable on 27 June were not effective. On 28 June a permanent splice in the towcable was made by the local telephone company, and the 2 previously inoperative transponders were repaired by an engineer from the manufacturer in California.

On 29 June, the search proceeded with renewed vigor and all equipment in working order. The transponders were set up at Schoodic Pt. and atop the 100 ft. radio antenna at Jonesport Station. The area to the northward of the datum was searched with no firm contacts. At this point the search party was learning how to deal with the rugged bottom topography and were not finding as many false contacts. This was due to the improved navigation in that the contacts could be regained and investigated. On 30 June the area to the south of the datum buoy was again searched, and a highly probable target was found at 1500.

The target was detected on the 200 meter range scale, as shown in Figure 30. The wood hull does not produce an image much different than some of the rock outcroppings that are so prevalent in the area, and which may be seen to the left of the target. The major cue used in identification was the shadow indicating the object is protruding sharply off of the sea bottom. The dimensions of the object were as expected for a 65 ft. vessel. Subsequent passes on the object showed several mid-water sonar echoes indicating the rigging of the vessel. Water depth at this location was 240 feet.

The configuration of TRAVELLER III was known to the search team. The search coordinator had ironically visited TRAVELLER III and the previous owner two years prior to this incident in the West Indies. Drawings of the vessel had been published as shown in Figure 31. Based upon information gathered from approximately 8 passes over the object, it was classified as TRAVELLER III with a 90% certainty in the identification.

Subsequent imaging of the target in conjunction with a salvage attempt on 25 July 1978 produced the image shown in Figure 32. The white portion of the image is the acoustic shadow. This is a view from the starboard beam. The vessel is sitting upright and the two masts, furled sails and bowsprit can clearly be seen. The towfish was 20 meters off of the bottom and the recorder was in the SURVEY mode for this image. When compared to the published drawing, there is little doubt that the object is in fact TRAVELLER III. Subsequent inspection by divers revealed approximately 10 tons of marijuana in the hull.

**FIGURE 30. Sonar image of initial contact on TRAVELLER III. Towfish altitude 35 meters, range scale 200 meters.**

## 61-Ft. Ketch TRAVELLER III

**SPECIFICATIONS:**

LOA....................62'-2"
LWL....................48'-0"
BEAM...................16'-1"
DRAFT...................6'-0"
DISPL...............71,000 Lbs
BALLAST (LEAD)......18,000 LBS
SAIL AREA...........1789 SQ FT
POWER (DIESEL).......70-120 HP
FUEL..................250 GALS
WATER.................300 GALS
CONST (DOUBLE).....CARVEL WOOD
PRISMATIC COEFF.......... .565

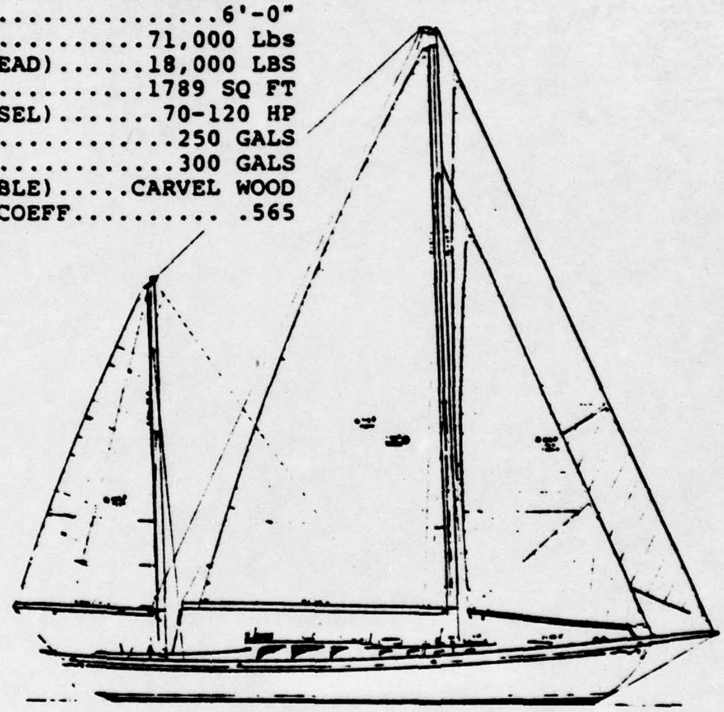


FIGURE 31. Reproduced from Cruising Designs Power and Sail by Edward S. Brewer.

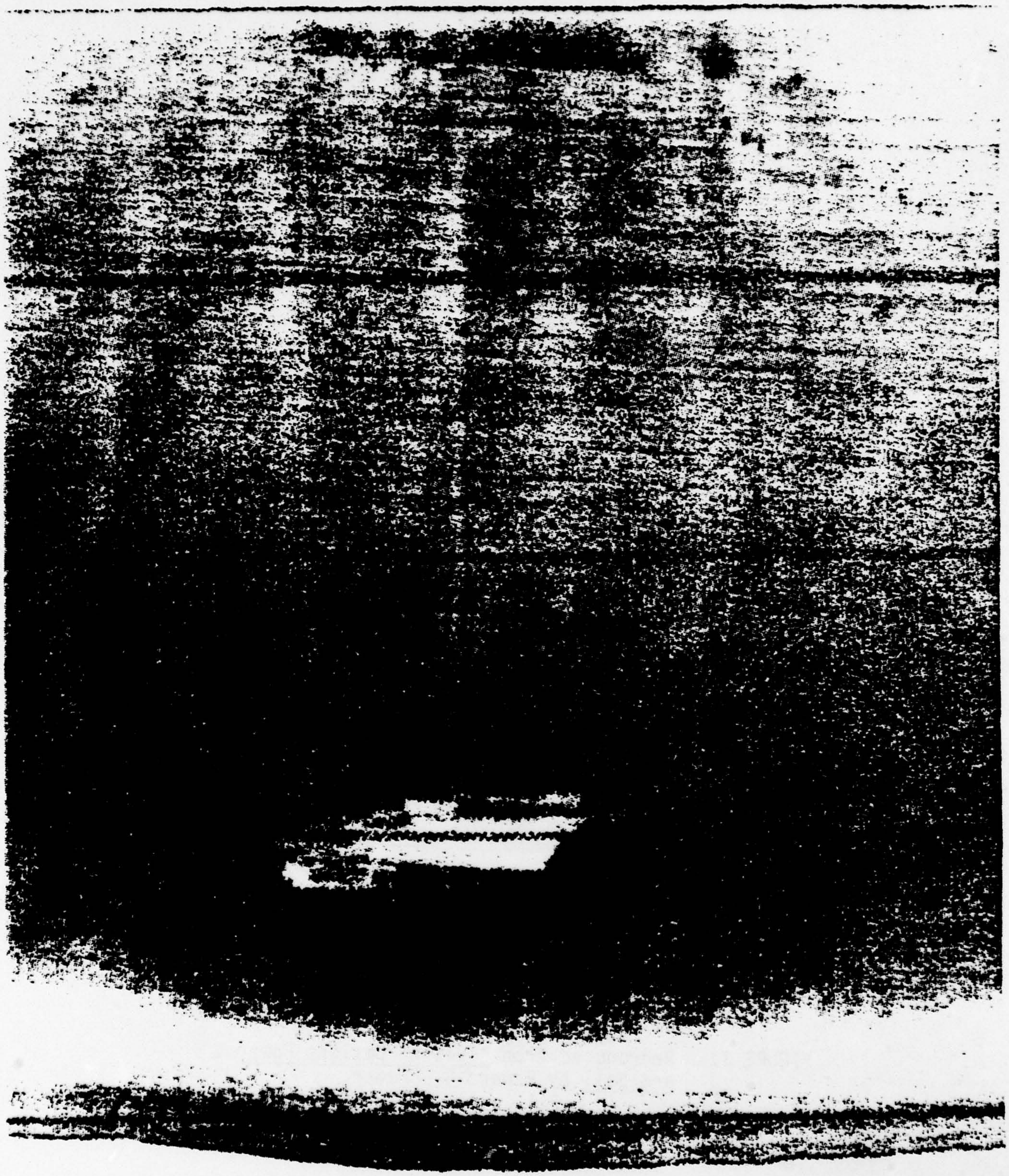


FIGURE 32. Enlarged sonar image of TRAVELLER III.
Taken by USCG Research and Development Center
using an EG&G Side Scan Sonar System.

## 9.2 LOBSTA I

The vessel is a 70 ft. steel fishing vessel that sank due to unknown reasons with 5 men on board approximately 40 miles SSE of Montauk Point, NY in 240 feet of water. On 23 September 1978 a side scan sonar search team was flown to the CGC Chilula, a 210 ft. medium-endurance cutter, on station as the search vessel.

The vessel was last seen in a capsized condition by a CG helocopter, who noted the LORAN-C coordinates. On the morning of 28 September a Navy P-3 Orion aircraft flew over the area with magnetic anomaly detection (MAD) gear and found 5 contacts. Two major search areas of approximately 3 by 4 miles each were designated based on the last sighting and the MAD contacts. A parallel Track (PSL) pattern based on LORAN-C lines 9930-Z was set up. These lines have a gradient of approximately 400 meters/microsecond. Since the resolution of the LORAN receiver was 0.2 microseconds, the inherent error in the navigational system was approximately 80 meters. The navigational system was marginally sufficient to conduct a search on the 200 meter range scale.

The sonar search started at 1700 on 28 September. The search was run continuously using a 3 man watch rotating every 2 hours on the sonar. This method was found to be most effective for a long-term sonar search. Once the search began, a severe instability was noted in the ship's LORAN receiver, which was being used for navigation. The receiver would unpredictably indicate a 10 microsecond error. This effect coupled with the low resolution prevented repetitive passes on any targets of interest. The sea bottom was noted to be flat and lacked geological features that would produce a false target.

A request to the R&D Center for technical assistance in navigation brought 2 improved LORAN receivers and a skilled LORAN system operator on 30 September. The navigation was shifted to the LORAN-C 9960 grid, which is a new and improved system replacing the 9930 grid. Using this improved capability, no instability was noted and the search was repeated in the most probable area. A firm target was encountered at 0122, 3 October.

The initial contact is shown in Figure 33. Since the sea bottom in the search area is featureless it was immediately assumed that the target was of interest, even without the effects of linear features or shadow. The steel vessel produced a dense, massive image. The location was marked by a small buoy during this initial pass. Subsequent passes were made after sunrise. The LORAN system was sufficient to enable the ship's crew to find the buoy, however, the buoy was necessary to make the short range passes with sufficient accuracy during the contact investigation.

The image shown in Figure 34 was obtained of a port beam view, showing the shadows of two masts and a wheelhouse. This image was later compared to a photograph of LOBSTA 1, Figure 35. Using the "length of shadow" method described in the section on contact investigation the following dimensions were found from the sonar image.

| | Sonar Image | Photography |
|---|---|---|
| Height of Wheelhouse | 3.1 m | 3.2 m |
| Height of Masts | 5.8 m | 5.1 m |

Height of towfish above bottom: 26 meters.

Using the above evidence, the target was classified as LOBSTA 1 with a 90% certainty. Subsequent inspection of the hull by an underwater TV System on 14 November showed that the target was in fact LOBSTA 1.

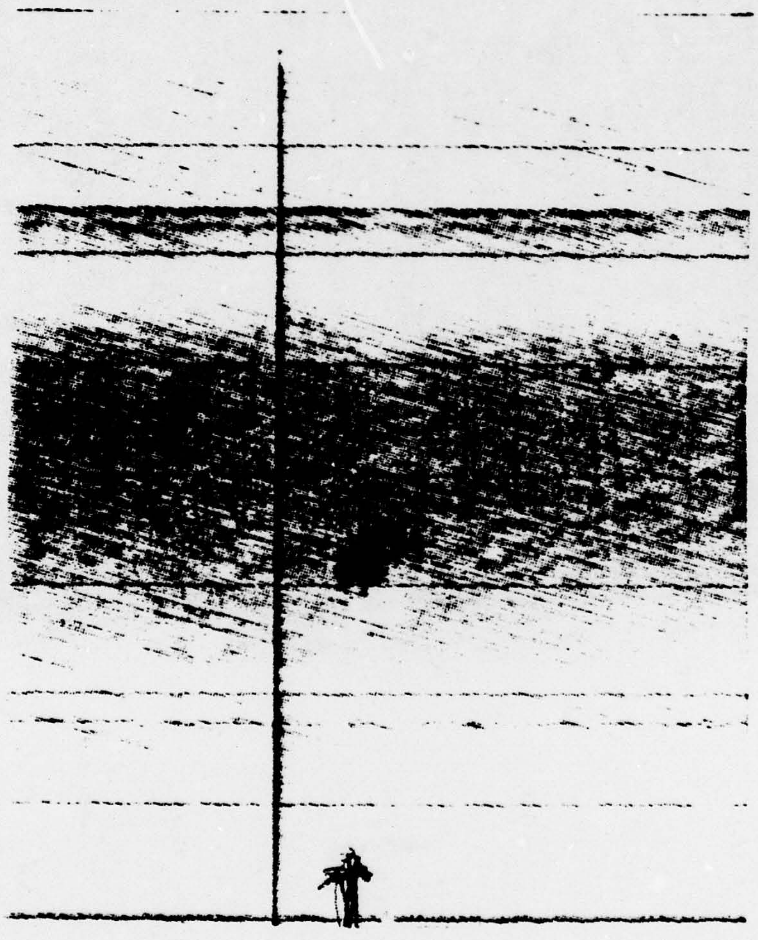


FIGURE 33. Sonar image of initial contact of LOBSTA I.
Towfish altitude 39 meters, 200 meter range scale.

FIGURE 34. Enlarged sonar image of F/V LOBSTA I. Taken by USCG Research and Development Center using an EG&G Side Scan Sonar System. Towfish altitude 26 meters, 200 meter range scale.

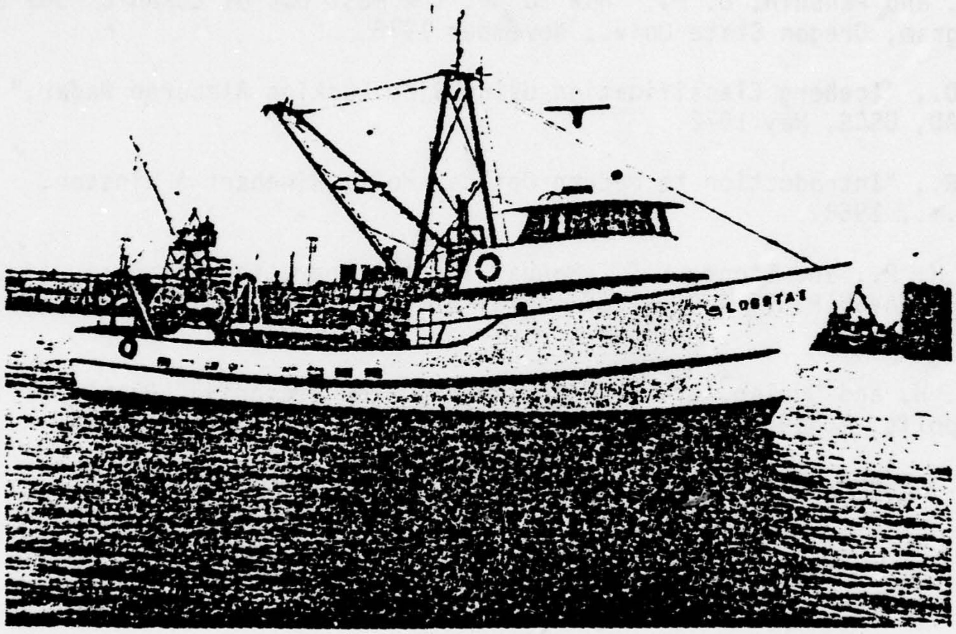



FIGURE 35. Photograph of the 70-foot fishing vessel LOBSTA I.

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## APPENDIX A

## TEMPORARY MARKER BUOYS

Temporary marker buoys have been used with great success by side scan sonar searches in the past in several notable searches in shallow water. They are especially useful during a random search to work a contact for further investigation. A marker buoy should always be kept at hand when towing gear over the side, in the event that the gear is lost a marker can instantaneously be set to enable a more efficient search to be conducted.

The Flip Buoy invented by Doc Edgerton at MIT adjusts itself to the water depth in order to more accuately work the target. It can be deployed quickly because of its small size and weight, and is inexpensive to build. The buoy consists of a flat piece of styrofoam about 2x12x18 inches. White, flat plastic jugs similar to 3 gallon oil jugs have also been used. A light mooring line with a length equal to the deepest water depth expected is wound around the buoy. A small cinder block or 10 pounds of lead will serve as an anchor. When the buoy is deployed, the mooring line unwinds until the anchor hits the bottom. The hydrostatic stability of the flat piece of styrofoam prevents the mooring line from unwinding any further and keeps the buoy at short stay over the anchor. Of course wind, waves and current would cause the buoy to further unwind over a period of time, however, by then the investigation is usually completed.

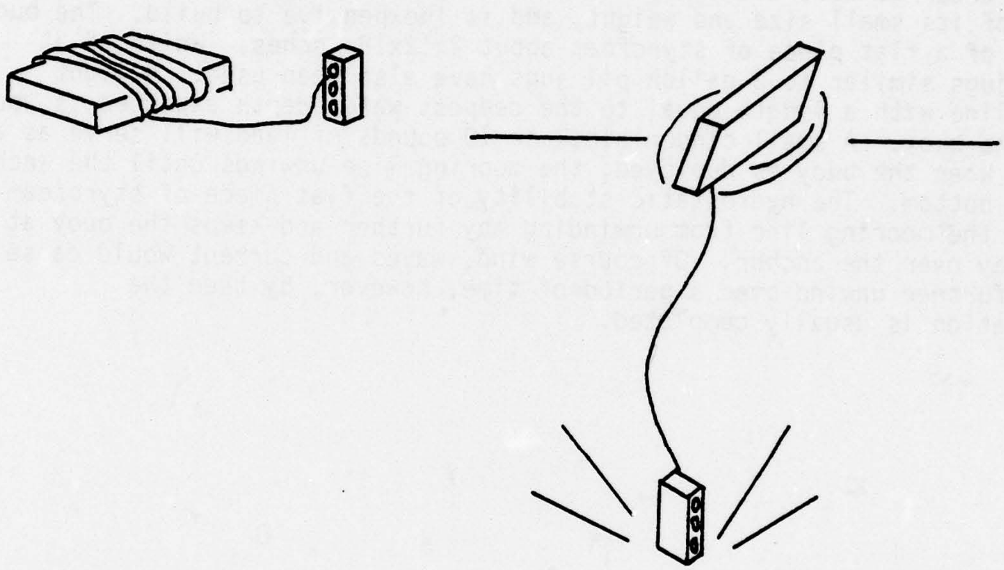
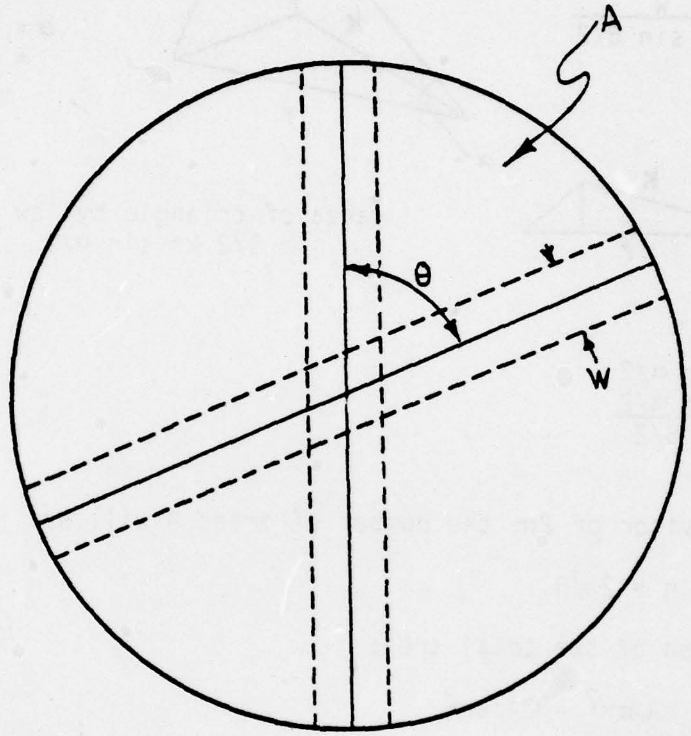


FIGURE A-1. EDGERTON FLIP BUOY

The mooring line is attached to and wound around a flat piece of styrofoam; the free end is attached to a small cinder block. When it is thrown overboard, the mooring line will unwind only until the cinder block hits bottom, thus keeping the buoy at short stay.

APPENDIX B

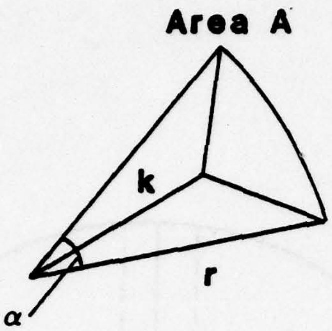
SECTOR SEARCH




θ is the central angle which is an integral divisor of 360°. The sweep width is W. A is the area which is left uncovered in the sector described by θ.

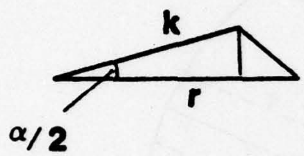
APPENDIX B

Area of sector $\alpha/2\pi\left(\pi r^2\right) = \alpha r^2/2$




$$k = \frac{W/2}{\sin \theta/2} = \frac{W}{2 \sin \theta/2}$$

$$\alpha = \theta - \theta_c$$
$$= \theta - 2 \arcsin W/2r$$




area of triangle by law of sines
$= 1/2\ kr \sin \alpha/2$

$$A = \alpha r^2/2 - kr \sin \alpha/2$$
$$A = \alpha r^2/2 - \frac{Wr \sin \alpha/2}{2 \sin \theta/2}$$

for $\theta$ integral divisor of $2\pi$, the number of areas A will be:

$$n = 2\pi/\theta.$$

and that proportion of the total area:

$$nA/\pi r^2 = 2A/\theta r^2$$

and the portion of the area is:

$$= \alpha/\theta - \frac{W/r\theta \sin \alpha/2,}{\sin \theta/2} \text{ where } \alpha = \theta - 2 \arcsin W/2r$$

## APPENDIX C

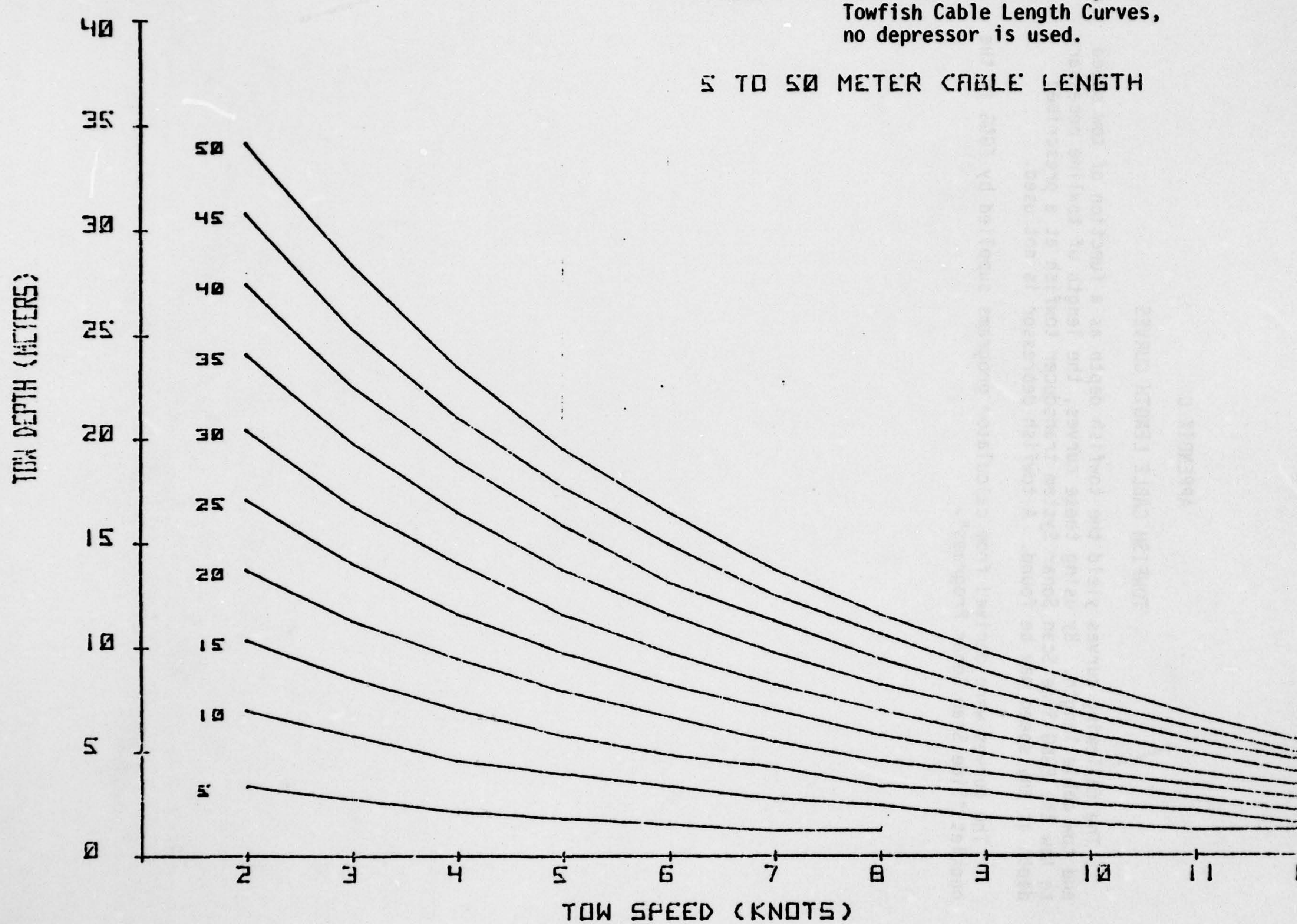
## TOWFISH CABLE LENGTH CURVES

The following curves yield the towfish depth as a function of tow speed and tow cable length. By using these curves, the length of towline necessary to tow the EG&G Side Scan Sonar System transducer towfish at a prescribed depth at any speed may be found. A towfish depressor is not used.

The curves were derived from calculator programs supplied by EG&G in the booklet "Side Scan Sonar Programs".

FIGURE C-1. EG&G Side Scan Sonar System Towfish Cable Length Curves, no depressor is used.

5 TO 50 METER CABLE LENGTH



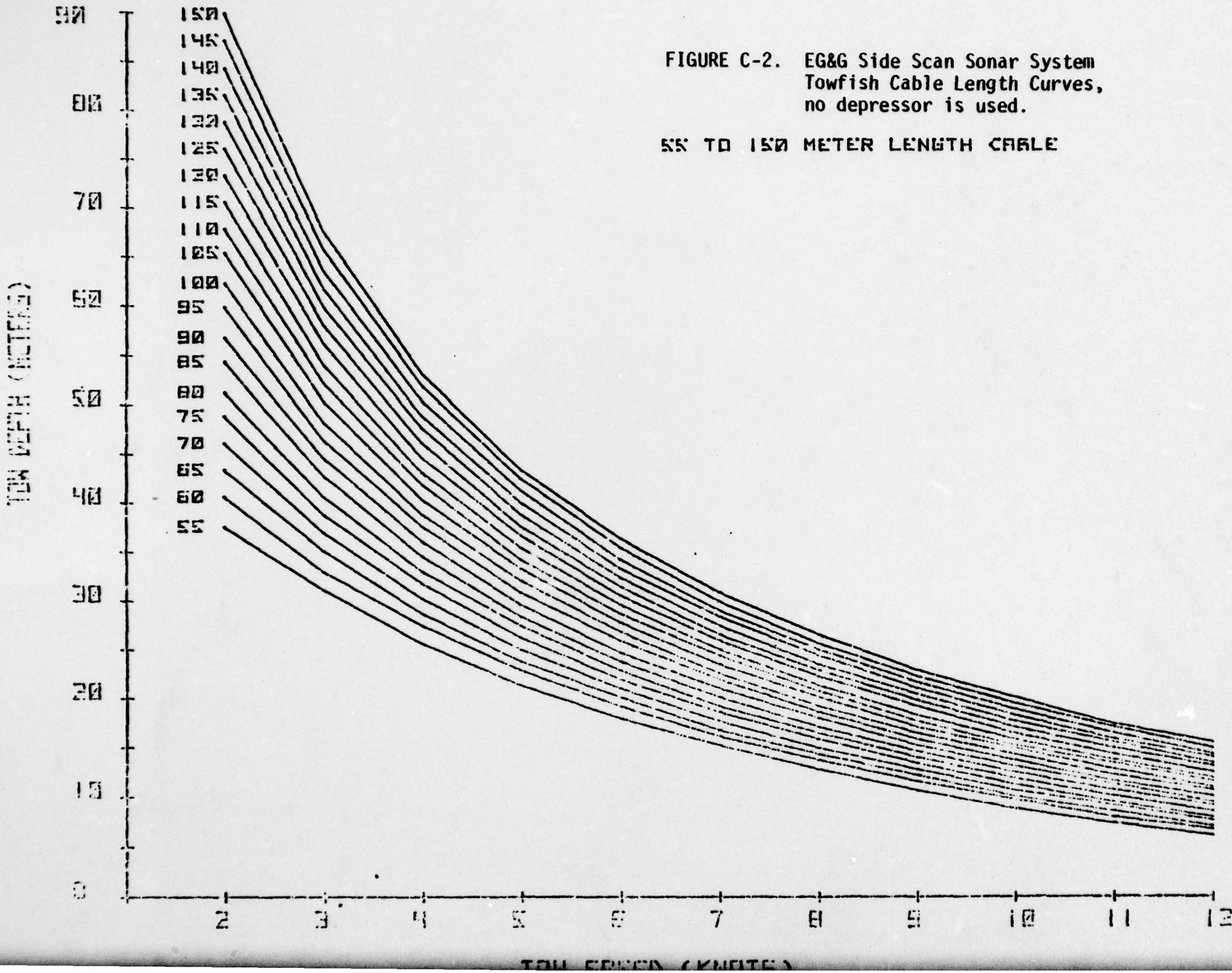



FIGURE C-2. EG&G Side Scan Sonar System Towfish Cable Length Curves, no depressor is used.

55 TO 150 METER LENGTH CABLE

F

5